The Royal Aeronautical Society

(FOUNDED 1866)

with which is incorporated The Institution of Aeronautical Engineers

No. 263. NOVEMBER, 1932. Vol. XXXVI.

PROCEEDINGS

NINTH MEETING, SECOND HALF, 67TH SESSION

A lecture, illustrated by lantern slides, and followed by a kinematograph film, was delivered by Herr Wolfgang Von Gronau on his flight from Germany to Chicago, on Thursday, April 28th, 1932. In the chair Colonel the Master of Sempill, Past-President.

The CHAIRMAN: Commander Von Gronau had come specially from Bahn to give his lecture at a very busy time, when many tests and conferences were taking place. He needed no special introduction to that audience, as his name was well known, and the work he had done to advance the cause of aviation. A few particulars of his career, however, might be of interest. Some 21 years ago he entered the Imperial German Navy, and a few years later transferred to the Naval Air Service. During the war he held many important positions in the North Sea and in the Baltic, and filled them with considerable distinction. After the close of hostilities, like so many good aviators, he took up farming for a period of years, and then came back into aviation, as Director-in-Charge of the Marine Training School, at Bahn, in Germany, where at the present moment he had under training some fifty pilots, whom he was instructing in the handling of the marine type of aircraft. In 1929 Commander Von Gronau conceived the idea of developing the route to America via Iceland and Greenland, and he took the old Dornier Wal machine that had been previously used by the late Dr. Amundsen in his Arctic flights, and latterly by Captain Courtney in his attempted flight across the North Atlantic, when he had to make a forced landing. He flew first of all to Reykjavik in Iceland, and then back again to Scotland, making an experimental survey. Realising in advance that he would not be able to get the permission of the German authorities to make the flight, as he intended, to New York, he decided that the flight was well worth making, and so he made it without the sanction of the authorities. The flight was such an astonishing success, and he was so acclaimed wherever he went as a pioneer and a great adventurer, that his authorities thought better of censuring him, and made him a presentation instead, giving him a pardon at the same time. Last year he made another flight along the same route, but instead of rounding the shores of Greenland, he flew across the Greenland ice cap, also in the Dornier Wal. He was undoubtedly one of the pioneers of aviation in Germany, particularly on the marine side, and his international viewpoint on the whole aspect of this matter and its future would be very valuable to hear.

IN A FLYING BOAT ACROSS THE GREENLAND ICE CAP TO U.S.A.

BY

COMMANDER WOLFGANG VON GRONAU

My flight from List, Germany, to Chicago, via Greenland and Labrador, was made in July and August of 1931. I had previously made a similar flight to America in 1930 when I chose the south point of Greenland and became very much impressed by this magnificently interesting country. Ever since that flight I had a strong desire to explore this country more closely. My desire for a second flight became acute when we, in Germany, received the first reports of the British Arctic Air-Route Expedition, under the leadership of Mr. Watkins.

Their weather reports for our prospective flight were very favourable and I immediately set to work to organise my second venture. I succeeded in obtaining the support and the assistance of the German Luft Hansa, the Association for the Cultivation of German Science, under whose auspices the Wegner Greenland Inland Ice Expedition operated, and also the support of the German Ministry of Transport and the Danish Government. All the preparations naturally caused a considerable delay in the start of my flight.

The trial flight to America of 1930 convinced me a little more that the route via Greenland offered practical possibilities. Of course, the route which I selected at that time over the South Point of Greenland did not appear the most advantageous and I therefore decided to repeat the performance over a different route. This time I intended to avoid long stretches of sea and fly from Reykjavik to the east coast of Greenland and from there straight across the inland ice to the west coast, and thence via north Labrador over the Hudson Bay to the middle west of the North American Continent. As our final goal we selected Chicago as it is the largest and most important commercial centre in the interior of U.S.A. Furthermore, our flight was guided by large lakes and rivers and the situation seemed ideal.

The crossing of the inland ice wastes of Greenland meant a flight of five hours at a height of about nine thousand feet over territory which was completely covered with ice and without any sign of life whatsoever. Although the great inland glacier offers here and there favourable landing possibilities for a seaplane, an emergency landing under unfavourable conditions would have necessitated a tramp of several weeks across the ice to safety. Consequently we had to provide suitable equipment and carry with us the necessary provisions for such an emergency. The risk, however, in crossing the ice regions appeared to me negligible in comparison to other great advantages which are offered by a flight along this route.

The proposed stages of this flight were a little better arranged than in the previous year and the stretches of sea selected were comparatively shorter. Arrangements were made to discharge our fuel quickly during the flight in case of emergency. We selected a plane with two engines so that in case one broke down we could carry on our flight for another two or three hours with the remaining one. These facts reduced the risks considerably.

In working out our route via Greenland, we had in mind to explore the possibilities of establishing a regular air route to America and to make a few reconnoitring flights along the east and west coast for the purpose of eventually establishing meteorological stations. We selected Godthaab, the capital town

of Greenland, as our main point for these surveying flights. We had previously sent Dr. Baumann, the meteorologist of the German Commercial Flying School, to Godthaab to render us the necessary assistance. The Danish Flight Organisation also showed great interest in our enterprise and for its own information had dispatched Mr. Petersen, one of their best known airmen, to Greenland to give us all the necessary assistance. All these preparations entailed a considerable amount of work.

With much trouble and a considerable loss of time the Dornier Wal (a later type of the Amundsen Wal used in the previous year) was at last completed and equipped with two B.M.W.7 engines of 700 h.p. each, made at the Bavarian Motor Works in Munich. The necessary instruments were only delivered at the last minute, and the short wave length radio apparatus, for which we had especially asked, could not be delivered, so that we had to content ourselves with an old heavy model which added unnecessary weight and proved of inadequate use to us on our flight. Further adding to our difficulties, I decided to take a film of the flight. I had selected the same crew as on the previous flight, but not one of us had any experience in taking films. Strictly speaking, I am not very eager to take photographs on such a flight as it deprives one of a most important item, namely, time. Pictures, however, form a real reminiscence of a flight and I stuck to my original idea, equipping our plane with a film camera and the necessary material. This, of course, meant more money, more work and, above all, more weight. Later on we did not regret the inconvenience incurred by taking the photographs.

Everything was ready; and then followed what every airman detests—a period of waiting for suitable weather conditions. Fog and storms held us up for several days. Finally we became impatient, grew tired of waiting, and when on August 7th a temporary local improvement but new depression was forecast, we decided to start anyway. Up to the Orkney Islands we had a steadily increasing head wind, dropping our speed to about eighty miles per hour. After a few hours' flight, a number of fishing smacks which we sighted below, created a little change. And when we were over the English Islands, we were able to establish a radio contact with Faroe, from which we learned that the weather conditions there had improved and that, at least for the last lap, we might expect better flying conditions. We safely reached and landed at the already familiar port of Trangisvaag. Here we received the first news of the American flyer Cramer, who had started from the other side to cover the same route which we were taking. He had just resumed his flight from a neighbouring fjord, where he had been compelled to make an emergency landing on account of damage to his engine. But that same evening Cramer had turned back when he encountered the terrible weather conditions which we had left behind us, and he landed in the Shetland Islands. The next day he became impatient and, although the damage to his engine was only superficially repaired, he took the risk in face of a storm to resume his flight to Copenhagen and fell a victim to his enterprise. He was forced down on the high seas, his light plane was dashed to pieces, and he was drowned.

We started the following day in glorious sunshine, but after an hour's flight we ran into a deep depression accompanied by fog vapour, low clouds and fine drizzling rain. The visibility was so bad that we had to descend to within a few feet of the water and pull in our antennæ. After an hour and a half the atmosphere cleared a little and we were able to make contact with the Iceland radio station, which informed us that the visibility over the country was fair, but that we must expect strong head winds. Meanwhile, we had made good progress and were no longer so anxiously concerned about our petrol supply. Over our starboard and through the mist and clouds we saw in the distance the summit of the mighty white Vatna Jökul Mountain, and found ourselves immediately off the coast of Iceland.

The following two days were occupied in filling our petrol tanks, overhauling our engines, organising the information service and weather reports, and in paying a few courtesy visits. This was my third visit to Reykjavik so that I was quite familiar with the town. Weather reports indicated bad weather conditions over the south of Greenland, so that we were in no hurry to resume our flight.

On the 13th of August the conditions were much the same. Reports from Greenland still indicated bad weather conditions over the south and the territory which we intended to cross. The conditions in the north, however, and in the neighbourhood of Scoresby Sound were reported to be good and favourable. In spite of considerable doubt as to landing conditions at Scoresby Sound, the danger of floating ice and our ignorance as to the possibility of anchoring our plane, we decided to break the monotonous spell of waiting and continue our flight. We made quick preparations for a start, and when I advised the German Consul of our intention by 'phone to start for North Greenland, and if weather conditions there did not permit crossing to the west coast to return the following day to Reykjavik, he was rather taken aback. He said, " If you tell me you will fly to North Greenland, it sounds to me as though you were going to the end of the world; and if at the same time you might return from your little excursion the following day, then I must confess that the airman's conception of this world baffles me."

Our northward flight started in a fresh wind and in the beginning weather conditions were fine. However, as soon as we left the Iceland coast behind us we encountered a wall of fog, and from then onwards fog and good visibility changed at regular intervals. About fifteen minutes' flight from the coast I crawled into the chart-room when a slip was handed to me containing the laconic word " ice," and upon looking out, instead of the usual sea water, as far as the eye could see we were over floating ice. At first it was thin ice which became thicker and heavier as our flight continued. Now and then a stretch of fog would obscure our view. We had to go up higher to clear heavy banks of fog, and when we emerged from them we were suddenly confronted by the high mountains of the east coast of Greenland, bathed in brilliant sunshine. It was a most impressive sight. The farther we penetrated to the north, the clearer the visibility became and there was hardly a breath of wind. The sea was perfectly calm, but so far as the eye could see there was ice and nothing else. We took a few photographs, particularly some of the first icebergs which we encountered, so that we might have a permanent reminder of this very impressive sight. Finally we became so accustomed to the ice regions that we came down very low.

After a flight of five hours we reached Scoresby Sound, the largest bay of the Greenland coast on the east. We saw nothing but floating ice and icebergs, and became a little anxious because, although the settlement was clearly marked on my map, we could not discover its location. But one is apt to misjudge distances in these mighty mountains. One imagines oneself to be quite close to them while actually one is a considerable distance away. After circling about along the coast and the bay, we finally discovered the little houses of the settlement dotted here and there. Our next trouble was to find a space on the water which was sufficiently free from ice to permit our landing. The colour of the water was dark blue and wonderfully clear, the surface was smooth and the mountains were beautifully reflected in it. When we struck the surface of the water on landing, we all had a feeling of great relief after our long flight over the ice.

Slowly we taxied towards the shore when suddenly our pleasant feeling was interrupted by a loud bang. At first we thought we had struck a heavy slab of ice and all the consequences flashed through our minds when, much to our relief, we noticed a smoke cloud drifting towards us from the shore and discovered that the inhabitants had greeted us with a shot from a mortar gun. We made

for the small landing stage and expected some assistance or someone to show us where we could make fast our plane. However, the people who were about showed no sign of movement, whilst shot after shot barked from the gun. We were told later that this was the highest honour accorded strangers to their shores.

Meanwhile we had roped our plane to a landing-post and for a few moments surveyed the wonderful scenery surrounding us. There was a blue sky, the wonderful clear water, the icebergs—a glittering mass of white and blue—the sound behind us and the snow-covered summits of the promontories. We enjoyed the perfect picture and, above all, the peaceful silence reigning everywhere.

Soon after our arrival we set to work and prepared for the next day. Our first attention was given to the petrol supply, and in a small harbour this is greatly facilitated as everything is close and handy.

At about nine-thirty p.m. we concluded our work and went to supper with the Governor of the settlement.

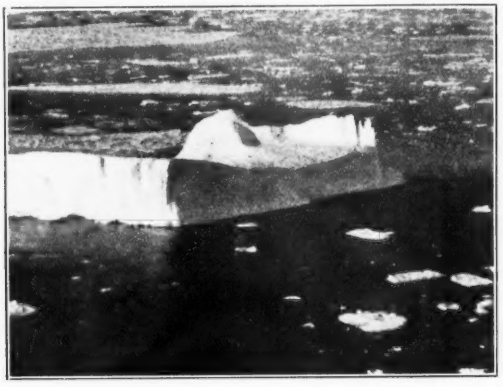

FIG. 1.

Typical water and ice seen on the flight.

The sight of the Greenland Eskimo types roused our curiosity. Their dresses suited to the climatic conditions were vastly different from our European wardrobe. Their boots consisted of so-called "kamiker," made of seal skins with the fur on the inside. They are warm and soft, do not look exactly smart, but are very practical and something like our airman's fur boots. As there exists neither road nor footpath one has to walk over stones and rocks to get from one house to another, which proves detrimental to our European leather soles.

The night was spent in the radio operator's house. We slept on the sofa in the best room and were greeted the following morning with brilliant sunshine and a blue sky. One felt beautifully warm in the sun and we had a feeling of being in St. Moritz. The important factor was the absence of wind; if the slightest wind had sprung up it would have cooled the air so considerably that it would have been rather uncomfortable.

Everything was so new and interesting to us that we felt like living in an ice paradise. Inwardly we hoped that the weather reports would remain unfavourable a little longer so that we might enjoy another day up here. This proved to be the case. Godthaab reported improvements, but advised us to wait a day longer.

We soon found that life in Scoresby Sound was not quite so lonely as we had imagined. An American millionairess, who was deeply interested in Arctic explorations, had chartered a little steamer in Norway and had announced her approach by wireless. Every year she collects a few friends and explores these regions. This year she selected the sounds of East Greenland and shortly after breakfast the ship arrived. This was a most exciting day for so remote a little settlement. A seaplane from Germany and a strange ship from Norway. You must realise what this means for the people of Scoresby Sound, who only see a steamer once every year for two or three days.

During the afternoon we accompanied the district Governor on a boat trip to a settlement of Eskimos, who were as yet untouched by civilisation. The conveyance consisted of a ramshackle petroleum-driven motor boat; the engine gave out right away and it required another hour and a half for repairs before we could start. Every half an hour we had to stop and clean out the engine. The people here were not very good mechanics. We did not quite cherish the

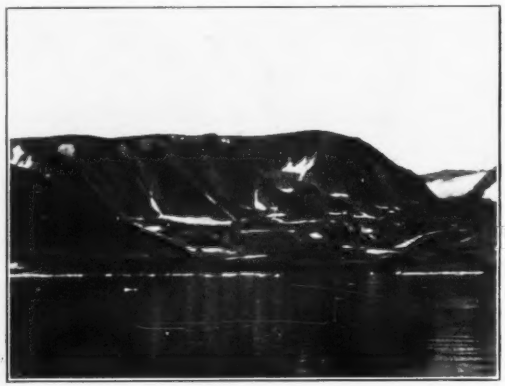

FIG. 2.
Near Scoresby Sound.

idea of the trip as we noticed that they had taken with them the necessary sailing tackle in case the engine gave out altogether. However, we finally managed to reach our destination, Cape Hopes. This boat trip proved of great interest to me in so far as it gave me some ideas of a possible landing in a seaplane between floating ice and icebergs. The ice seen from the air often looks like a solid mass, whilst in reality it has sufficient wide channels which would make it possible for a seaplane to come down and paddle along inside these gaps. A close view reveals the fact that the floating ice is not as dangerous as it looks from the air.

On the following day, August 15th, the weather remained fair and reports from everywhere indicated favourable conditions; but heavy clouds were reported from Angmagsalik. We therefore decided to risk a start from Scoresby Sound straight across the inland ice to Godthaab. Our difficulty was that we had to carry petrol to last us for ten hours, fly along the fjords for at least one and a half hours, after which we had to obtain a height of about six thousand five hundred feet. If, as planned, we had flown over Angmagsalik we would have required petrol for only five hours to cross the inland ice, which would have made the plane considerably lighter and the flight much easier.

The start for Godthaab did not come off as smoothly as we expected. The front engine would not start. For an hour we floated amid the ice. I finally

gave up and decided to return to the shore and make a thorough examination. But as things always do happen, just as we reached the shore, the engine started and we immediately turned round. We flew over Cape Hopes where our Eskimo friends of the day before and the Boyd Expedition waved us a final farewell. We then passed over the peninsula called Jamesland, which is free of ice and the only point on the east coast of Greenland where the musk ox can exist. We soon spotted a herd of them and on our approach they became alarmed and in their fright formed a ring round a big looking bull. From above the formation looked like a star; they stood perfectly still until we had passed over them, after which they took to flight.

The deeper we penetrate into the Sound the more unpleasant it appears to us below. Soon we can hardly see any water, due to icebergs and floating ice. But all this provided good opportunity for taking photographs. When we reached the end of the Sound we became a little anxious. The mountains were already about eight thousand feet high, sudden bad squalls were buffeting our

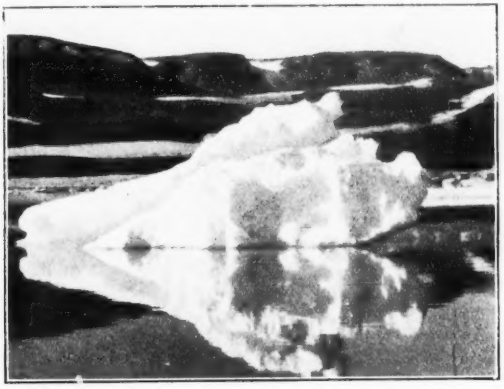

FIG. 3.

Near Scoresby Sound.

plane considerably and we encountered a strong down wind, so that our boat with full throttle did not obtain the necessary height to permit a crossing of the inland ice. We therefore made our way with much difficulty over a few lower glaciers, and although we hoped to see the inland ice at any moment, we were time and again confronted with new and still higher mountains which we either had to surmount or encircle. It took us an hour to clear these promontories which were not indicated on our map; even when we had cleared these obstacles and had succeeded in reaching the inland ice, the latter rose so rapidly that we had to continue to fly under full power. Those were difficult hours for us because, as you will know, we intensely dislike to run our engines at full speed, and at that time we were not sure whether we would succeed. Our plane, because of the emergency equipment which we carried, was a little too heavy. We began to climb gradually to a height of ten thousand feet, the highest point which the inland ice reaches. I felt confident that an emergency landing could have been effected without accident as the inland ice is perfectly flat; but in spite of our polar equipment, it would have been extremely difficult for us to get back to Scoresby Sound or Angmagsalik, the only inhabited parts along the three thousand kilometre east coast. Our equipment would only have served

a useful purpose in case of an accident of a lighter nature. We mainly relied on the fact, that if one of our engines gave out we could continue our flight for two or three hours with the remaining engine. Actual facts, however, taught us that in the thin air we had to run both our engines at full throttle in order to keep the necessary height.

After we had at last obtained the necessary height and thought that all difficulties had been overcome we suddenly encountered a fresh obstacle in the shape of low clouds, mist and snow directly in the middle of the inland ice. The visibility became practically nil, we were unable to gauge our height, and at the same time the danger of ice coating commenced. With difficulty we avoided the areas where the snowstorm appeared worst. It was a horrible feeling to fly blindfolded into a black wall. To crown everything, my radio operator suddenly reported that our antennæ was dragging through snow, and I had thought that we were at least six hundred feet above the ice. These adverse weather conditions lasted for an hour and a half when all at once the atmosphere cleared and we encountered sunshine again. Hour after hour passed flying over this desert of ice. The horizon around us appeared higher than our position in the air, and as far as the eye could see there was nothing but a flat white surface. The farther we flew onwards and the lower we descended the warmer the atmosphere became and we were in hopes of soon seeing the coast. However, black clouds appeared again and our anxiety was still unrelieved. The only consolation which we had was that the temperature was rising considerably and below we noticed some thaw. The ice began to appear dirty and large cracks were visible.

The west coast of Greenland, as you know, receives a little warmth from the Gulf Stream and during the summer is at times free of ice. Everywhere we noticed little streams and here and there lakes were forming. This part of the territory is, of course, quite unsuitable for walking. It should not be long now before we reached the coast. At long last we saw the chain of mountains along the coast. Strangely, whilst flying over the inland ice our radio contact completely failed for more than five hours, and during this part of our flight we remained entirely without any news or reports whatsoever. As we neared the coast we were able to pick up, suddenly, messages of high intensity from the radio station of Godthavn, but it was not possible to take a proper bearing as apparently the magnetic conditions over the inland ice are so unfavourable that a considerable diversion occurs. The variation of the compass during our flight was from forty to seventy degrees. But as we had had a considerable spell of sunshine we were able to ascertain the exact correction which was necessary to obtain the right direction.

If we thought when approaching the coast that we might soon encounter water by flying along a fjord or over a glacier, we were again disappointed, because the Holstenborg district towards which we were flying is preceded by a chain of mountains about two hundred and fifty kilometres wide.

At this time our maps were useless and we were unable to define our exact position. We therefore had to wait till we could locate a geologically registered mountain or fjord. At any rate, we knew we had to steer south, and from a message received learned that there was a blue sky over Godthaab. The farther we flew the more we realised that we could only reach Godthaab with our last drop of petrol as our climbing efforts had used up too much of our fuel. I therefore decided to make for a little place called Sukkertoppen, which is about an hour's flight from Godthaab. Luckily we were able to make contact with the radio station at Godthaab and informed them of our change of plan. They replied that the harbour of Sukkertoppen was well situated and sheltered and that they could send us a supply of petrol from Godthaab in a day. We finally came to a glacier which sloped down to the mouth of a fjord. From the map it was clear that this was the Eternal Fjord.

Just as it was getting dark we came down in the harbour of Sukkertoppen, which to our surprise was quite an appreciable little town. A whole crowd of Eskimos and Greenlanders had assembled on the shore. The next moment our plane was surrounded by a mass of little boats. The entire population had turned out to view the first aircraft they had ever seen. My second pilot and I went ashore to be received by the Governor and the Danish Colony. Our eardrums had been dulled by the constant noise of the engine and we returned immediately for a rest. None of us ever had slept so well as during that night!

The next day we had completed the refilling of our tanks and were ready to continue our flight to Godthaab. We started off and on our way received a radio message not to land right in the harbour, but in front of the colony as the Governor and the inhabitants had prepared a special reception for us. The wind and weather conditions were favourable so we agreed to their request.

After anchoring our plane we stepped on shore and the representatives of the colony approached us to deliver a welcoming address which we did not understand.

FIG. 4.
Godthaab Fjord.

As the weather was favourable the following day we decided to take a reconnoitring flight along the coast. But when we were occupied in preparing for a start, a treacherous wind sprung up and blew a mist over us from the sea which, unfortunately, foiled our plans. These mists form over the ice and the slightest wind will blow them inland. The mist stayed with us until the following day, August 18th, when the sun came out and cleared it. In spite of a bad head wind we managed to slide out of the harbour and flew south to Ivigtut, the place at which I landed for the first time in Greenland on my previous flight.

We came down at Ivigtut, but landing in a small harbour and in shallow water is always a difficult matter.

On the following day we still had fine weather conditions, it was perfectly calm and in the bay there was little ice at that time. There is, at any time, less ice on the west coast than on the east. On our flight back we noticed a small leakage in the radiator so we had to land at Godthaab and repair the damage. After that we continued our reconnoitring flight northward, but had only flown about half an hour when I noticed that the temperature of the front motor had risen considerably. We throttled down one engine and gave full throttle to the other motor, but the same trouble immediately arose there too. I changed my

course at once as I anticipated serious trouble. We commenced to jettison petrol; however, quicker than we could find a remedy the trouble developed and thick clouds of steam and oil came from the rear motor. Nevertheless we reached Godthaab harbour safely.

We stripped the rear engine and examined the cylinders. Most of them were in good condition, but the last two pistons had seized and were burned. Luckily we had with us two spare pistons, and with no other serious damage in the front engine, we were able to effect the repairs ourselves. The situation was not without hope, provided good weather conditions continued and made the work in the harbour possible.

Now followed a week of hard work. When the dismantling of so large an aeroplane engine is an intricate job to the best experts of the motor works, you can imagine the immensity of our task under most adverse conditions. We had to work under all sorts of difficult obstacles, of which the main one was that the engine had to remain on the plane and every precaution had to be taken that no parts—nuts, screws, bolts, etc.—fell overboard. The loss of the smallest part, which we were unable to replace, would have landed us in a very awkward situation. Whenever a high wind sprang up and the water became rough, our operations became greatly endangered.

To describe the repairs in detail would entail too much time. Be it sufficient, therefore, to tell you that one difficulty after another turned up. For instance, we had to cut out the pistons by handsaws and even the gudgeon pins. As they are hardened steel, this was very slow hard work. We also had to dismantle the front engine but, luckily, found no serious damage. Finally the day arrived when our two engines were reassembled and once more ready for a trial. The question was, would they work properly? We had lost so much time that cold, rain and heavy storms set in—a sign that we were approaching the autumn season.

The rear motor was very hard to turn, in fact it would not respond and we were afraid that there might be a crankshaft bearing out of order which would have meant another week's work. Nothing would persuade the rear engine to move so we left it and tried the front one, but here also we met with a similar difficulty. Nothing doing!

The next step was to take the starter to pieces and examine it closely. More work! When this was done, I suggested using a little ether to coax the motor, as a small dose is often successful although dangerous. Trials of half a day were unsuccessful so we gave up until the following morning, when, much to our relief, we were greeted by glorious sunshine and a warmer atmosphere. After some more hard work the front motor suddenly commenced to run, followed by the rear motor. This and the following day were occupied with trial flights, but after each flight little adjustments were necessary until we were satisfied that both engines were running as smoothly as possible and that we could risk the continuation of our journey of another three thousand miles. A good part of this distance would be over lonely water and totally unknown land.

On the morning of the 28th of August reports from everywhere were favourable, but in spite of the fact that we had to expect a strong head wind all the way, we decided to start. On account of the engine trouble, I had to keep the load as low as possible and could only take just enough petrol to last out the journey. Everything that was not absolutely necessary was left behind. After a consultation with our meteorologist, the start was made. We had in mind to look for a petrol depot which the Canadian Government had established a few years ago; but of its actual existence we had no definite information.

In good weather our flight began—the sea was calm and the visibility good. After an hour we met a north-western strength four, which was quite sufficient to indicate that we could not possibly reach our destination. Fortunately the radio connection was good and we got into touch with the radio station on

Resolution Island, asking them for information about the various petrol depots on the Labrador coast. Resolution Island told us that they had orders from the Canadian Government to deliver to us any quantity of petrol that we might require, but we did not find the water suitable for the landing of such a big boat.

Soon we found ourselves over the Hudson Strait and were approaching an island which was indicated on the map as the Akpaktok Island. Whilst in ordinary circumstances one would be glad to see an island, we felt differently and decided to hurry away from this sixty-kilometre rock of basalt where there was no sign of any living creature. No ship would have found us here as an approach to this island would have been quite difficult. We continued on our way and soon came to the east coast of North Labrador. The mouth of the Payne River was easily seen, although on the map it looks quite different to what it is in reality. We were glad to see a small settlement with a real sailing ship before it, but it looked too insignificant to have been important enough for a landing. Our maps were becoming useless; we had three of them on board and each was different from the other, and the reality was different again. Even if we had had correct maps it would have been difficult to use them as a guide, because there was one mass of rocks with thousands of water holes and little pools; they all looked alike and were linked up with one another. I therefore decided to fly only according to my compass to the west coast and find there some reliable orientation. This course should have led us to a large bay on which we hoped to find a trading station of the Hudson Bay Company, Povugnituk, and incidentally, a petrol dump.

The land beneath us rose gradually to a height of about twelve hundred feet. The temperature was rising and a nice healthy freshness was noticeable in the air. However, no living creature was to be seen anywhere; everything looked dead and deserted. At last we found that we had crossed the water; little streams took a westerly course and the land began to slope gradually. The sun was setting and it was high time that we should reach the coast. We could only hope that we had steered the correct course, but as we were fairly near the magnetic pole, there was a misdirection of fifty degrees and the power of direction of our compass was becoming steadily weaker so that we had to find our direction from the sun. At last the coast was in sight. We thought we recognised our destination, Povugnituk. We saw houses, but on coming closer discovered that they were only canvas tents. And as there was a small boat anchored before them we decided to land as it had become dark and we could not continue our search and use up the small quantity of petrol left. We came down on the water and with eager eyes surveyed the camp. Taxying towards the shore, we came into shallow water. We avoided the danger by making for the anchored boat and tied our plane to it.

After a while one or two of the inhabitants came, and when they found that all was safe the rest of them followed. Soon we were surrounded by a number of Kajaks, but all attempts to enter into conversation were in vain. We tried German, English, Danish, and also the international seamen's language, but all we could extract from them were some un-understandable, inarticulate sounds. They greeted us with loud yells and gave vent to their pleasure by laughter. They looked at us and our plane with wondering eyes. We frequently mentioned the name Povugnituk which was the place for which we were looking and each time it was answered with a nodding of the head. In mentioning other names they seemed to understand what we wanted to know and pointed out the direction. From their indications we gathered that we were in the neighbourhood of Povugnituk. Finally I succeeded in worming out of them a few English words which helped me considerably. I repeatedly mentioned Hudson Bay Company and white men and suddenly received a reply in English " House, house—twenty mile," and they indicated the direction.

We decided to wait for daylight and to continue our search on the following day. At any rate we were pleased that the repairs of our engines had proved so successful and we had safely reached the North American continent. Our only trouble now was to take our plane to Port Harrisson for refuelling. Our petrol indicator was out of order and we were unable to ascertain the amount left until the following morning. We remained on board our plane and prepared a little supper by means of a spirit lamp. The Eskimos were very curious, and boatload after boatload of men, women and children came rowing over to us to inspect our plane. They examined everything very closely and touched the engine and other parts so that we had to mount a sentry to keep them away. We soon crawled into our sleeping bags, which was a slight change from our hotel in Reykjavik and our residence with the Governor of Godthaab. It was a warm moonlight night and on land we could see the camp fires of the Eskimos.

On the following day, August 29th, we rose early to prepare for the continuation of our flight. We were still doubtful of our whereabouts. We saw that the life of these people was the most primitive as well as the laziest I have ever seen. In the morning they took out their kajaks and picked up the nets which they had let out before, pulled out some big salmon, and since the food for the day had been found, their work and toil was ended. A further attempt to make myself understood failed, so I returned to the plane to resume our flight in search of petrol. We carefully paddled out of the shallow water and rose into the air. But unfortunately the rain increased and the visibility became worse. We searched the inner bay without any success. We changed our course southward, but no helpful signs seemed to turn up. We flew towards many a rock as we thought we had spotted a house. Occasionally we thought we saw a ship, but each time, upon nearing the object, we discovered nothing more than a rock. Our petrol supply was becoming exhausted. I had just decided to give up the search in this direction and to return north so that in case of emergency we might land once more at the Eskimo settlement, when my co-pilot pointed to me another settlement. It had to be the right spot and we had to find some petrol. We flew very low over the houses, but to our surprise there was not a sign of a living creature anywhere. The post seemed deserted and our spirits dropped. However, if the barrels which we already saw from above, contained petrol, we were simply going to take it and get away.

We landed and carefully taxied into the mouth of the river. We anchored quite close to the shore and took our rubber boat and rowed ashore to ascertain our fate. We had a race amongst us to get to the barrels. One after the other the barrels were pitched up and each time we were disappointed until we found one half full, and the last one completely full. What a relief! Our own supply was just about finished, and if we had to remain here without fuel, no one knows what our fate might have been. Harrisson was another hundred miles away and the country in between was uninhabited and quite impassable.

Fate indeed was very kind to us and this was the second stroke of luck which we had on this day. Meanwhile the weather had cleared and we made an inspection of the houses. The doors were all closed and locked. This settlement consists of six houses, but we were quite unable to ascertain the name of the place. We put the barrels on our rubber boat and rowed them to the plane. It was a difficult manœuvre, but it succeeded and we filled up. We prepared a mid-day meal and felt so pleased with the world that we indulged in the luxury of an afternoon nap. After waking up, we made preparations to start once more. We succeeded in getting into the mouth of the river all right, but the outgoing journey proved a little more difficult. Before we were free to start we had to manufacture some oars and row out to steer clear of the rocky ground. Visibility became very bad, and our maps were absolutely useless. We had a very strong head wind and could only move very slowly, and the petrol consumption

was enormous. I decided to continue the flight until we reduced our stock of petrol to a minimum, hoping to find another Eskimo settlement. The last moment the weather cleared and we found ourselves within easy reach of Harrisson. Once more we were greatly relieved and soon landed in the harbour of Harrisson, where we spotted the steamer with our petrol supply. When we examined our petrol, we discovered that we had only enough left to last us for five minutes. And that was the third stroke of good luck we had on the same day.

We were surprised to find another seaplane in this small and deserted harbour of North Labrador. We found out that it belonged to the American airman Preston, who, as a substitute for the missing airman Cramer, wanted to undertake the northland flight via Greenland over the inland ice. After we left them we heard that the weather conditions were so much against them that they thought better of it and turned back homeward.

On August 31st it was very cold and there was a light north-westerly wind blowing, clouds were low and a drizzling rain was falling. The barometer, however, was rising; the cold was getting very unpleasant and a sweat was noticeable on the walls of our plane. We decided to continue the flight immediately. The rain increased and the visibility became bad so we came down to one hundred feet and flew along the rocky coast. We were considerably cheered by a message from Fort Churchill that fine weather conditions were prevailing at Long Lake, which was our next destination. So we decided to stick it.

The coast of North Labrador did not look as dangerous as I had expected; there were a good many bays and some of them even had sandy beaches. Now and then we saw the tents of an Eskimo settlement and altogether everything appeared much more convenient for an emergency landing. After a short while we found ourselves over the wooded regions, and for the first time in four weeks we saw trees.

For the next three hours we flew along over endless tree-tops until we finally saw the first railroad lines. They ran as straight as a die from east to west and we were fast approaching civilisation. We saw a second railroad line and a train which we followed and soon came to our destination, Long Lake, where we landed and made ourselves perfectly comfortable on board. That night it was raining heavily, but our plane proved absolutely watertight and we felt comfortably sheltered inside.

On the following morning we began refuelling. The barrels containing the petrol were conveyed one by one on two Canadian canoes tied together. This was the only means of transporting them from the flat shore to our plane. Whilst we were busy preparing for a fresh start, we received a message from Chicago that everything was prepared for our reception. We were thrilled and lost no time to start for our final destination. Everything was completed so we took off from the lake. Again we had to be extremely careful about our petrol as we had a long journey before us and our supply was only just sufficient. We passed over Long Lake, which seemed to be without an end. When we cleared it we encountered high mountains. They looked magnificent, but were detrimental to our petrol supply as we had to climb higher to clear them. After a while we arrived at Lake Superior and the atmosphere became more and more misty. We encountered a fog, but having received a radio report that conditions over the land which we had to cross to reach Lake Michigan were good, we climbed over the fog and continued our flight cheerfully.

Every radio station in this vicinity was in communication with us giving us weather reports and directions. We passed over Milwaukee and soon after that Great Lakes, the naval station where we landed in the year 1930. This time we had been asked to come right up to Chicago so that the people could see the landing and our plane. We had just sufficient petrol and at last we were circling

over the skyscrapers of this gigantic city. This was our second experience and once more we came down and landed safely in the harbour. We slowly glided along to the quay.

In due course we had to prepare for our departure via Cleveland to New York, where our flight ended. At our start from Great Lakes, we had to surmount another obstacle. The water in the harbour had fallen considerably and our plane became so embedded in sand that it proved impossible to move it. A fire engine was immediately summoned and with the help of an American high pressure fire hose the plane was finally refloated.

Our flight to Cleveland was uneventful.

On the following day our flight ended in North Beach Airport, New York, and our plane Grönland Wal was safely anchored beside the great Do X. Fate would have it that the steamer " Hamburg " of the Hamburg-America Line should play an important part in connection with our ventures. In the previous year she brought us and the seaplane Amundsen Wal back to Germany, and shortly before starting this flight we had occasion to circle round her in the mouth of the River Elbe. When we arrived in New York this time, the steamer " Hamburg " was again ready to receive us and the Grönland Wal for shipment back to Germany.

On account of the uncertain condition of the rear engine it was not advisable to risk a flight back over land and sea such as we had just crossed. Upon arrival in Hamburg our plane was re-assembled and we flew back to List on the Island of Sylt, from where we had started.

I thank the Danish Government for the assistance I received. For the success of this flight I am further indebted to Commander Gossage, the British Air Attaché in Berlin at that time, the Department of National Defence at Ottawa, and the Shell Oil Company who, under great difficulties, were able to deliver petrol and oil for our benefit to the most impossible and outlandish places.

It was only after I had completed this flight that I obtained a copy of Admiral Byrd's book on his South Pole flight. I could have learned much from his descriptions of his experiences in flying over three-thousand-metre high plateaux. His description of unknown mountains, and his observations generally, showed a great similarity to our flight.

Discussion

Admiral Sir W. E. Goodenough (President of the Royal Geographical Society): Only posterity gave full justice to the pioneer and gave him credit for his work. When people were flying quite casually across to America, he was sure that they would hold the pioneer aviators in honour in their minds. Those who composed the present audience and who navigated the air had many problems before them. He would mention only one of them, namely, the formation of the land and its effect on the local conditions of the weather. It seemed that at a height of 5,000, 8,000, or 10,000ft., the weather was fairly stable, but when one got over a coast with deep ravines and great precipices, such as were found in Greenland, the alterations in weather that had to be coped with were very considerable. There were tremendous variations and rapidly rising storms on the coast of Greenland, and the difficulty of dealing with these, especially when there were also large differences of temperature at different heights, must be considerable. This might be expected to have a great effect on where to have the landing places, as to whether one would be able to land right on the coast or further inshore, or whether in time to come there might not be a possibility of having landing places further out at sea. That was a problem which certainly required a great deal of thought for its solution.

He was glad to hear the lecturer refer so often to his compasses and other instruments. He had often insisted upon the necessity of having every conceiv-

able kind of instrument which was likely to be useful. It might be almost a heresy to say it, but he for one felt inclined to give up ten gallons of petrol to get that 75lbs. available for the best possible installation of instruments.

He could tell the lecturer, with regard to what he had said about Akpaktok, that he would have found no one there unless he had happened to meet Mr. Clutterbuck's expedition which went there last September. He congratulated Commander Von Gronau, not only on the admirable work he had done, but on the charming and modest way in which he had presented it.

Colonel SHELMERDINE (Director of Civil Aviation): They were very much indebted to the Commander for his extremely interesting account of a very notable flight. Time was very short, and he would be extremely brief in his own remarks. He did not think that any of those who had listened to this lecture and seen the photographs would have any very great confidence in the possibility of organising this route as a regular commercial air route. The lecturer did not say anything on that point, and if there was time at the close he hoped he would give his considered opinion as the result of the flight which he had described to them and the one which he had carried out previously.

Colonel HARRY BLEE (Director of Aeronautics of the Department of Commerce, U.S.A.): He wished to add a word of appreciation at the opportunity of being present and hearing this most interesting lecture. He also wished on behalf of his Department to express appreciation of the many courtesies and the very generous hospitality that had been extended to him while witnessing the interesting developments in aeronautics in this country. He had seen many interesting things in London and in England generally. As for the question that had been raised as to the practicability of a commercial air route, following the line that had just been discussed and illustrated in the most interesting photographs shown by the lecturer, he really was not in a position to speak with any authority on this matter as he had not had the opportunity of making a study of the potentialities of the route. He could not help being impressed, however, by the various points that were brought out by the lecturer and by the many difficulties which he had overcome—difficulties which to many might seem almost unsurmountable.

Group Captain GOSSAGE: Commander Von Gronau had kindly referred to the part which he (the speaker) had played in helping in the organisation of his flight. All, in fact, that he did was to assist in relations with the Canadian Government as regards the provision of maps and the location of petrol depots in Northern Canada. As regards the provision of maps, he was not apparently very successful! The lecturer had obtained three different maps of the same locality which, in practice, were found to differ from one another, and all three differed from the reality! Therefore whether it came about or not—and they would all be glad to hear the lecturer's opinion on the subject—that this route became a practical proposition, there was no question that the survey of the route was one of the first things that would have to be undertaken. That point had impressed itself more than anything else on his mind in the course of Commander Von Gronau's remarks.

Mr. H. G. WATKINS: His own expedition spent a year in Greenland studying the conditions and the possibility of an air route on the east coast and on the ice plateau. After a year's work, flying and travelling and taking weather observations, and generally mapping the country, they came to the conclusion that there would be no difficulty at all in having a route all the year round and flying on practically every day. Unfortunately, they did not have planes suitable for making a demonstration flight, but the demonstration flight was made by Commander Von Gronau and showed, as he had said, that this air route would not be difficult if there were suitable bases. Of course, on Commander Von Gronau's flight he had not the opportunity of making many advance preparations,

and this fact, with the lack of suitable bases, must have added greatly to his difficulties.

Mr. WORDIE (whose name, the Chairman said, was well known in both Arctic and Antarctic exploration): Commander Von Gronau seemed to be quite unbeatable, whether he was risking a rupture with his superior officers or facing the ups and downs of the weather on his trip last year. The flight seemed to the speaker specially notable, as Commander Von Gronau simply went straight ahead in spite of all difficulties and always found a way out. The commercial development of the route had certainly been greatly advanced by this flight, for Commander Von Gronau had used a machine which was approaching the commercial type.

Mr. A. J. T. TAYLOR (who, the Chairman said, was concerned with the organisation of the projected mail-carrying route from the United States through the Arctic to Europe): He had played a very unimportant part in negotiations between the Trans-American Corporation and the Governments of Iceland, Greenland and Denmark. That Corporation some three or four weeks ago obtained a concession from Iceland, and two days ago the Danish Government gave it a licence to conduct preliminary and serious exploration in Greenland in order to satisfy themselves on the feasibility of a route from Detroit to Copenhagen, a distance of only 4,396 miles.

Major COTTON: He could not do more than add his congratulations to those tendered to Commander Von Gronau and confirm what Mr. Watkins had said about the feasibility of establishing this route. From his own experience of flying in Labrador, it appeared quite a possible thing to do, given proper stations and proper equipment.

Commander C. N. COLSON: It would be useful if Commander Von Gronau would tell them what methods of navigation he used when out of sight of land and when over land which lacked distinctive features. Did he use any form of sun compass? Also, how did he check the abnormal variations which he quoted as being of 40° or 50° at certain times?

Mr. COURTAULD: As one who had had an intimate experience of the centre of the ice cap, he was afraid he had nothing to add. He was not an airman, and he knew nothing about flying, nor was he a meteorologist, but he had enjoyed hearing the lecture, and would like to hear further what the Commander thought about the future possibility of this air route.

The CHAIRMAN: Before he asked Commander Von Gronau to reply, he would like himself to stress some of the points raised by other speakers, and particularly Commander Colson's query as to the methods of navigation. Perhaps Commander Von Gronau would be good enough to furnish appendices to his paper containing more technical details of the methods of navigation than he had given in his lecture, which necessarily was of a somewhat popular character. He had only referred briefly to the question of ice formation on the wings of his machine, and apparently he had encountered this only to a small extent on his journey. But he knew that he had studied the matter fairly completely, and he would like to ask him how he proposed to deal with such ice formation when these projected lines were in operation. It would also be interesting to hear something about the take-off of his machine in these peculiarly flat calm conditions. He hoped that Commander Von Gronau would come back to them before long and tell them more about his work.

REPLY TO DISCUSSION

It was always difficult to speak about a long journey in a short time, and as he had not wanted to bore his audience he had had to leave out many interesting details, including a number of scientific things, especially meteorology. They had a meteorologist on the west coast and on board, and a number of

meteorological instruments, whereby they could compare observations at 9,000ft. Various interesting facts were elicited, but he thought the best thing he could do was, after his return to Germany, to send over some of these details in order that they might be printed in the report of the discussion.

The same held good with regard to the instruments of navigation. He carried a number of instruments, especially compasses. He agreed with what Admiral Goodenough had said that the compass was the soul of a long-distance flight. He took a big compass and some smaller compasses, representing various kinds. As for the method of navigation, the best method this time was the wireless direction finder. He always obtained a very good reception, except on the flat over the inland ice, so that he could take bearings from Scoresby Sound from the moment they left Reykjavik, and when they left Godthaab, they had Resolution Island. He had also on board a good stroboscopic instrument, which was also very important. They used no smoke, but it was possible to put that instrument to some good use. They had also a sun compass, but it was an old model, the same as that used by Amundsen on his polar flight, and so they did not like to use it over much. Flying with that instrument was very easy, and much more comfortable than flying with the magnetic compass, but, as he had stated, there was too much head resistance as a rule. When crossing the ice cap and crossing North Labrador, the time was round about six o'clock in the evening, so that they always had the sun in the west, and could every half-hour take the variation and read their course.

As for maps, he recalled that one of the most important people in Canada told him, when he asked for maps, " We have some, but we shall have to leave it to the next generation to make better ones." When on the flight over North Labrador he understood why they had left it to the next generation, as there was nothing apparently to gain in that country, and when he looked down over the land which was traversed, he felt that perhaps it might not be the next generation, but the generation after that, which would provide the maps.

With regard to ice coating, he had had a good deal of experience in the winter air traffic in respect of ice coating, but no remedy had as yet been found. The Americans were trying out the plan of using the exhaust gases for heating the parts which were most liable to coating, but he thought the ice coating would be an important matter in establishing an air route over the Greenland ice cap. From his observations, it appeared likely that the temperatures which gave ice coating over the Greenland ice cap would be possible for six months of the year.

He thought that, given reliable organisation, it would be possible to make this a regular route. The present dangers and difficulties arose from the fact that there was no organisation and no possibility of help in the case of an emergency landing. But he for his part would prefer to fly as he did the first time from Reykjavik to the south of Greenland, and from there to the south of Labrador. There, he thought, the possibilities were much better. He dare not say that flying was possible for the whole year, but if it was possible to establish an air route for only six months of the year it would be a season's work and a great success. The Americans had pointed out to him that they had been flying for three years over the Rocky Mountains, and they thought that much more difficult than flying over the ice cap. That might possibly be the case, but it required a big organisation, otherwise there might be some losses which would be avoidable if one was flying more to the south where one could make contact with a ship. It was out of the question to discuss the possibilities off-hand, as one always had to consider the meteorological situation. The subject would come forward next year, which was International Polar Year, and as a result of the discussions which would follow he thought it might be possible to arrange a service which would be quite reliable.

Meteorological Report

(Translated.)

After strong cyclonic activity had prevailed over the north-west part of the Atlantic Ocean at the beginning of August, on the 8th August a change occurred in that an influx of cold air from the North Sea brought an end to the hitherto changeable weather. The low pressure system last passed through, deriving energy from the temperature contrasts between sea and continent, still asserted itself over North Europe. A convergence line clearly arising from the winds could be followed from North Finland, over central Sweden, South Norway, and the North Sea to the English Channel (Denmark and German North Sea coast, south-west winds; west coast of Norway and east coast of England, north winds). The increase of pressure over the British Isles—over the North Atlantic, south-west of Iceland, lay an extensive area of high pressure, caused particularly in the zone between Scotland and South Norway a considerable pressure gradient, which assisted by stemming effect on the steep coast of Norway, produced strong winds in this region (Utsire—North 8, Shetland Isles—North 5), a familiar occurrence in this region with rapidly occurring changes of pressure.

Apart from the strong winds, the atmospheric conditions appeared fairly favourable, and particularly on the last part of the first stage one could reckon with decreasing winds. Meteorological information had been supplied even during the days preceding the start by the Seeflugreferat of the Deutschen Seewarte, and on the basis of their forecasts the 8th August was chosen as the first favourable day for the start. The flight has shown that from the general atmospheric conditions it is possible to obtain a sufficiently accurate idea for the individual flight sections. Thus the above mentioned convergence with its typical atmospheric influences was clearly observed over the North Sea during the flight. The convergence zone, however, embraced a region of 300 kilometres in diameter. Eastwards thereof, over the North Sea, cumulus clouds were encountered with fairly strong west winds (No. 5 Beaufort). Before the convergence was crossed, that is to say while still in the zone of the west wind, the oncoming northerly ground swell was perceptible, heralding the approach of the strong north wind which was subsequently encountered. In consequence of the frequent showers, visibility varied considerably. Clouds gathered quickly and covered the sky, when under 4° west longitude this convergence was passed. The wind veered to the north after it had shortly before blown from the west with southerly component. From this zone heavy ground swell was reported which had developed considerably with the north wind which had continued since the 6th August. After flying for about two hours under unfavourable atmospheric conditions (overcast, thick clouds, showers, and varying visibility) the weather gradually improved, the cloud layer broke up and the showers decreased, although at first contrary wind and ground swell continued unabated. Visibility, which was now reduced only by occasional showers, allowed good observation in the region for which we were making. It was no longer possible to continue the flight direct to Reykjavik, owing to the strong headwind of approximately 40 m.p.h. over the North Sea. Consequently, when the Orkney Islands were reached the course was set towards the Faroe Islands. On this stretch the decrease in the pressure gradient to the west had the effect of decreasing the strength of the wind to No. 2 while it still maintained its northerly direction.

(2) *Flight Section: Faroe Islands—Iceland*

There were no important changes in the total distribution of pressure. The Atlantic area of high pressure was still growing and extended over the British Isles and further eastward. Only in its northern part, in the Faroe Islands zone, was there a disturbance, which was embedded in the zone of high pressure over

the North Atlantic in the form of a flat trough. The axis of this trough, the wind system of which exhibited a pronounced convergence south of Iceland, had to be traversed in the flight from Trangisvaag to Reykjavik. Also near the Faroe Islands the wind already reacted to the tongue situated west of the islands, and in the course of the forenoon had veered from the north to south-west.

In spite of a cloudy sky, visibility was at first very good (50 nautical miles) until, after an hour's flight, it decreased owing to a rising mist. The weather encountered during the second hour's flight was extraordinarily typical of the different weather phases in the region of a developing tongue. The wind veered, while constantly weakening, right round to south, and finally dropped completely. Then drizzling rain fell, which soon turned into a shower, and in the following north-west wind at the rear of the tongue, again left off. The weather cleared, but the clouds remained very changeable. The strength of the wind was Beaufort No. 2. On nearing the coast, in the vicinity of Portland, the wind freshened considerably owing to coastal influences. Besides this increase (strength No. 5) the wind changed direction parallel to the coast (gradient wind N.W. 2, on the south coast W. 5). The Reykjanes peninsula, which projects far to the west, was crossed, as by doing so the flight to Reykjavik was shortened by about 70 kilometres. Many flights were made across the Reykjanes peninsula when atmospheric conditions were favourable during the Iceland flight in the summer of 1929, as reported by Soltau in his contribution to the aeronautical meteorology of Iceland (see Annalen d. Hydrogr., March, 1930). When the weather is not favourable these crossings can be difficult, and subject the pilot and the aeroplane to great stress. Over the ground, which was approximately 600-700 metres high and rose rather steeply from the sea, lay a closed cloud pall, sinking at the southern edge of the peninsula to about 200 metres, to the north, and on the north coast (Faxa Bay) approaching the windward side. The oblique position of the lower limit of the clouds gave a very clear picture of the turbulent air obstruction. The greatest gustiness was, however, encountered when approaching the shelving coast at the south. At 2-3 kilometres from the rocks the Dornier Wal was seized by down gusts and was often driven down 150-200 metres. These down gusts made it necessary for the machine to turn about in order to avoid collision with the mountains. The machine was flown a short distance out to sea again in order to gain height. At the second attempt the pilot succeeded in bringing the machine directly to the lower limit of the clouds over the dangerous zone of descending currents. It was found possible to utilise a valley opening into Faxa Bay for flying below the cloud pall which was sinking northwards.

The extraordinary gustiness on the Iceland coast, more particularly over Reykjanes, is one of the most notorious phenomena met with in flying in Iceland. It is noteworthy that the Swedish airman Ahrenberg in his flight to Iceland also encountered at this point gusts of wind of such force that he could not hold his machine.

In Reykjavik a halt of two days was provided to allow for preparations for the flight over the inland ice. The route planned was Reykjavik—Angmagsalik (east coast)—Godthaab (west coast). Reykjavik and Godthaab have almost the same geographical latitude of approximately over 64 N., whereas Angmagsalik is a good 1° to the north. The whole of this stage was to be flown in a day with a short intermediate landing in Angmagsalik to take on petrol. Thus the stage was divided into two equal portions each of which took five flying hours. Given favourable weather (following winds) or if there was ice obstruction in the harbour of Angmagsalik, a continuous flight was planned.

The aeronautical reports which on the flight to Reykjavik were supplied exclusively by the Deutsche Seewarte, Hamburg, now became more comprehensive, thanks to the assistance of the Meteorological Institute of Reykjavik. As

is well known, the main difficulty of aero-meteorological forecasts resides in the lack of correct knowledge of *local* weather influences. This is particularly exemplified in flying over unknown and difficult country as Greenland, with its formidable mountains and varying coastline formation. In order to meet this requirement adequately, further safety should be provided by erecting an aero-meteorological station on the west coast. For this reason the meteorologist of the Deutschen Verkehrsfliegerschule, Warnemünde, was sent to Godthaab a few weeks previously. His stay there was employed in obtaining information regarding the coastal weather and the possibilities of flight, and the relation between the coastal weather and the general atmospheric conditions. Details regarding this will be dealt with in a special section later on. We may, however, say in passing that certain local weather types can be predicted very reliably from the general character of the weather by means of the weather chart. The reception of the wireless weather reports was kindly undertaken by the Danish telegraphist at the wireless station at Godthaab, who also attended to the wireless communications with the "Wal." Above all, during the flight an attempt was made to increase the weather reports of the Greenland stations. Three-hour weather reports were made, all of which converged at Godthaab. On the basis of these reports it was possible to draw up a fairly reliable weather chart for Greenland; however, consideration had to be given to the fact that all meteorological elements, particularly the wind, are subjected to local influences. Moreover, the air pressure is not determined at all stations by means of a mercury barometer, but often by means of an aneroid barometer, and consequently the measurements recorded are not very exact. No great importance should therefore be attached to the absolute value of the air pressures mentioned; given sufficient knowledge of the local conditions, it generally suffices to follow the *changes* in air pressure—the relative values. The information regarding the weather thus obtained formed the basis of the weather consultations. The weather forecasts went by wireless via Julianhaab to Reykjavik, and reached their destination in good time, so that corresponding arrangements could be made for the day in question. The time taken by telegrams from Godthaab to Reykjavik was only about 15-20 minutes. Thanks to the assistance of certain leading personages in Greenland, in addition to the usual wireless service, a thoroughly frictionless transmission of weather reports was arranged.

(3) *Flight Section: Reykjavik—Scoresby Sound*

The start arranged for the 12th August to Angmagsalik could not be made owing to bad weather, particularly on the east coast of Greenland. Since arrival at Reykjavik the atmospheric conditions over the Atlantic Ocean had hardly changed. The high pressure, south of Iceland, covering the entire space between the Azores, Iceland and Ireland, remained stationary at undiminished strength. At the west flank of this area of high pressure, warm masses of air of the South Atlantic flowed in southerly winds towards the Denmark Strait, and at first developed only weak cyclonical activity over South Greenland. On the 12th August a core of low pressure lay over the south point of Greenland, the circulation flow of which caused a pronounced stemming effect of the moist ocean air masses on the south coast of Greenland. The mountains near Angmagsalik were completely covered in clouds and heavy rain also fell. No change in the weather was to be expected in the next few days, as the tendency for the pressure to move was extraordinarily small. The West Atlantic area of high pressure had a very restraining effect on the speed of movement of the cyclone, which otherwise is very high in this area. On the other hand, this meant further persistence of south-east winds in the region Iceland—Greenland, that is to say, a continuance of the stemmed weather conditions on the south-east coast of Greenland.

Not until the 13th August was movement in the distribution of pressure perceptible. These changes were particularly noticeable from the strong fall in pres-

sure over Iceland which occurred again for the first time during the last weather period. Owing to this situation, no good flying weather could be expected on the route to Angmagsalik the next day, 14th August. Moreover, a deterioration of the weather over Iceland, where owing to the influence of high pressure the weather had been good for several days, was certainly imminent. With the movement of the cyclone over South Greenland eastwards, the normal distribution of pressure was re-established. High pressure over the continent of Greenland, but over South Greenland only in the form of a narrow wedge of high pressure, for over the Davis Strait there remained a residual area of low pressure of the South Greenland cyclone, sending off a flat tongue north-eastwards over the central part of West Greenland. It was, however, difficult to gather from the weather reports of the Greenland stations that the extension of the high air pressure would make further progress. The centre of gravity of the Greenland area of high pressure lay as usual over North Greenland, and did not yield during the period of bad weather over South Greenland. These weather reports were communicated regularly to the " Wal " during its stay in Reykjavik (on an average twice a day).

In view of the unfavourable atmospheric conditions on the direct route Reykjavik—Angmagsalik—Godthaab, it was decided to evade this bad weather by flying via Scoresby Sound, which, being situated in the core area of the high pressure, had reported good weather for several days (see chart 3). At 3.40 p.m., 1.8, a start was made for Scoresby Sound. According to the distribution of pressure, easterly winds (0.3) prevailed over Iceland which, as a result of sinking, meant cloudless weather and good visibility. The " Wal " flew round the Snaefels peninsula and then the course was set for Staalbjerg-Huk, the westerly point of the north-west peninsula. Off the coast of this peninsula lay an extensive fog area, which extended several kilometres seawards, namely, this fog extended so far over the land that a great part of the coastal mountains were hidden. Towards the sea the height of this fog decreased and dissipated into separate strips of fog which lay on the water, so that at a distance of a few kilometres from the coast it was possible to fly at an altitude of 600 metres, and at times, between the streaks of mist a fairly high ground swell on the sea could be seen. The reason for the formation of this mist, which was driven from land seawards by weak east winds, has nothing to do with the atmospheric conditions prevailing on the day in question, as the dynamic influence of the movement of the air had rather a cloud and mist-dissipating effect. A proof of this was the decrease in the height of the clouds towards the sea and the gradual change of the cloud into separate streaks of mist. It is probable that this is a case of fog residues from a foggy area, which on the day previous had formed from low strato clouds (dynamic clouds at W.N.W. 3) and light rainfall, strengthened by night radiation, had formed over the mountainous north-west peninsula.

Such fogs are reckoned among the typical weather phenomena on the oceanic islands, but can be foretold only by good knowledge of local conditions.

Over the Denmark Strait the altitude of flight was 400 metres. It is very remarkable that shortly after the northern latitude of Iceland had been traversed, hardly 50 metres from the north coast of Iceland, drift ice was sighted. This meant that the drift ice limit had moved a relatively long way southwards; in normal circumstances the drift ice only comes so far southward in spring. Thin ice mist had formed in the middle of the Denmark Strait, probably attached in its spatial extension with a ground inversion, for at an altitude of 400 metres a temperature of +1.5C. was measured, further north—at a similar altitude—the temperature sank to +1.0. This relatively high temperature certainly justifies the assumption of ground inversion. As a reason for the atmospheric heating, the dynamic processes on the southerly slope of the East Greenland area of high pressure may be mentioned. In accordance with the dynamic heating it was cloudless, and the visibility was also very good aloft. The coast of Greenland

was sighted at a distance of about 200 kilometres. The drift ice mist, owing to the changing qualities of the drift ice, was very unevenly distributed.

Start from Reykjavik 3.40, land at Scoresby Sound 8.45.

(4) *Flight Section: Scoresby Sound—Godthaab. Inland Ice*

By fixing on the route via Scoresby Sound, the inland ice stretch was nearly doubled in comparison with the Angmagsalik—Godthaab route originally planned. From the *technical standpoint* it meant almost double the load of petrol, and this had to be carried to a height of at least 3,000 metres. With regard to *navigation*, the difficulty was that no terrestrial criteria were available for this stretch, and there was no possibility of determining wind influence and drift, whereby the normal difficulties were doubled. From the *meteorological* point of view, a considerable section of unexplored territory had to be considered. The only criteria are the reports of the few coastal stations, which on the narrower part of South Greenland permit an interpolation in respect of the weather elements (pressure, temperature, wind) rather than in the central part, where the " inland ice weather " is a more formidable factor.

The atmospheric conditions of the previous day had shown that contrary to widely propagated opinions, air pressure disturbances occasionally move over the continent of Greenland without meeting with any considerable resistance.

On the 14th August the flight over the inland ice could still not be undertaken, as the west coast in the Godthaab district was completely veiled by thick clouds and mist. These conditions occur very frequently there when south-west winds prevail. The actual cause of the bad weather was still the residual area of low pressure over the Davis Strait resulting from separation from the South Greenland cyclone, the tongue of which area of low pressure directed N.N.E. had been separated from the wedge of high pressure extending further over the inland ice. In a similar manner, the core situated north of Godthaab withdrew to the west. Everywhere there was a strong rise in pressure; at the same time the improvement in the weather extended along the west coast from south to north. The few weather reports from the stations on the coast permitted a very good weather synopsis, from which it was fairly certain that, on the next day—the 15th August—the weather would clear also in Godthaab. A corresponding weather report was wirelessed at mid-day on the 14th August to Scoresby Sound. Our supposition had proved to be correct. The cloud pall broke up and the clouds dispersed quickly. The wind veered from south-west to south and then to east. Thus the atmospheric conditions for crossing the inland ice were favourable and safe. Further weather reports received on the morning of the 15th August completely confirmed the tendency of development assumed on the previous day. The forecast telegraphed on the day before was: " High pressure axis Fredericshaab moving northwards towards Scoresby Sound. Godthaab district still on north side. Improvement continues. On south side weak east winds. Good flying weather probable." On the morning of the 15th August the following telegram was received: " South Greenland—' high ' further strengthened—flight route along divergence—weak, mostly east winds, bright. West coast clear." The clear weather on the west coast was, in a certain sense, the sign for the start, for owing to the slight possibilities of orientation due to inexact charts, it was absolutely essential that the weather should be completely satisfactory on reaching the west coast. During the flight certain difficulties were experienced in picking up the direction in spite of the fact that atmospheric conditions fulfilled expectations.

At 12.20 a start was made in Scoresby Sound. Owing to masses of ice at the starting point, the start was difficult, particularly as the " Wal " carried a full load and there was almost a dead calm. The southern arm of the Scoresby Sound, the Gaase Fjord, was selected for the ascent. In the narrower part of

this fjord, where the drifting ice masses are very compact, there is not sufficient room for landings. In this respect the area of the ice fjords on the east and west coast of Greenland must be included in the difficulties encountered in flying across the inland ice area. At the end of the Gaase Fjord was an immense glacier which was connected with the inland ice. A part of the journey had to be flown at full throttle in order to attain the altitude of 2,500 metres (the marginal height of the inland ice). Here it was clearly demonstrated that the topographical chart of the Greenland coast was very inexact. For instance, at an altitude of 2,500 metres, behind the actual marginal mountains, we came across a second mountain chain not indicated on the chart. Not until we had crossed this second mountain chain did we reach the uninterrupted surface of the inland ice, the margin of which was here 2,700 metres high. Some idea of the enormous dimensions of this marginal area over which we flew (fjord, glacier and marginal mountains) will be gathered when one considers that the flight from Scoresby Sound to the inland ice took about $1\frac{3}{4}$ hours, the distance being approximately 250 kilometres.

In this section the weather was quite clear, cloudless, the visibility was very good, and the winds were gentle. Far in front a few cirrus clouds appeared on the horizon. In order to shorten the distance over the inland ice, the course was not set directly for Godthaab, but for Holsteinborg, 300 kilometres to the north. This considerable alteration of the course northwards, which was not taken into account in the weather forecast, was soon to make itself felt. After flying for $2\frac{1}{2}$ hours over the inland ice, a few cumulus clouds appeared which extended in westerly direction and passed into nimbi. On reaching the highest point of the inland ice (after a flight of $2\frac{3}{4}$ hours over the inland ice) the clouds hung down almost to the surface of the snow; from some of the clouds there fell a slight shower of snow. The altitude of flight was 3,000 metres, only about 70 metres above the ground, so that for a time the antennæ was dragged through the snow. Here it was impossible to estimate the altitude, and the horizon also, owing to optical illusion, appeared to be considerably raised all round. Further, there was no criterion for estimating the direction and strength of the wind. The low, hanging clouds made it necessary for the course to be changed to 30 further south, in order to make for the light strips of sky visible to the south and to the left front. At this altitude the temperature was $-1°C.$—the most dangerous temperature for the formation of ice—and for this reason it seemed imperative not to fly through the clouds. The temperature of $-1°C.$ at an altitude of 3,000 metres, is a relatively high temperature and corresponds exactly to summer weather in Central Europe. After the previous weather period this is quite understandable; the area of high pressure over the West Atlantic for about eight days on its west side, in the region Iceland—Greenland, had caused warm sub-tropical air to penetrate far to the north in an unbroken stream. The source of air spread over this part of Greenland must be sought in southern latitudes. Why should not such an interchange of air—such as is usual over the European continent—be possible? The phenomenon is only much more rare because such a pronounced high pressure area over the North Atlantic signifies an abnormal distribution of air pressure. These atmospheric conditions prove that the Greenland ice, in any case the southern part, sometimes loses the character of a true polar area. In this case, an Atlantic " low " moved unhindered over South Greenland. The heavy clouds encountered mid-way over the inland ice, was nothing more than the warm air gliding up in the area of the wedge of low pressure of the Davis cyclone. Thus this wedge of low pressure was met in consequence of the northerly course. On the last third of the stretch of inland ice the weather again cleared up, *i.e.*, the machine now flew on a more southerly course back into the fine weather zone. After flying for fully six hours over inland ice, the westerly margin of the Holsteinborg district was reached. Cloudless weather with excellent visibility facilitated orientation otherwise ren-

dered so difficult by inaccuracies in the chart. The last part of this stage of the flight was accomplished outside the fjord on the coast.

Start at Scoresby Sound 10.20; land at Sukkertoppen, 20.15.

The stretch of coast Sukkertoppen—Godthaab, a distance of 70 kilometres, was flown in cloudless weather and north-east winds on the 16th August. Oncoming heavy fog at a high altitude, which gave the impression of a cirro-stratus layer, could be taken as a herald of more bad weather. (South-west winds aloft.)

On the following day, 17th August, the south-west wind reached the ground and blew at strength No. 4. The clouds were very low and hung directly on the coast, some reaching the ground.

From the sea coast station Feringerhafen, situated 100 kilometres south of Godthaab, south-west wind No. 8, low clouds, and rain were reported. The reconnaissance flight to Ivigtut planned for this day, which would lead over the inland ice, had to be abandoned. The bad weather zone was, however, confined to the Godthaab district, which is a frequent occurrence with local disturbances over the Davis Strait. The pronounced high pressure weather of the previous day still prevailed over South Greenland (District Ivigtut in Julianehaab).

Reconnaissance Flights: Godthaab—Ivigtut on the 18th August, and Ivigtut—Godthaab on the 19th August

The start was not made until 12.15 on the 18th August, and the weather was misty at Godthaab during the forenoon. It was one of the morning mists usual with S.W. winds, which disappear only with increasing insolation at mid-day. On the coast, with the exception of a little residual mist, there were no low clouds, while the clouds at a medium height (*i.e.*, stratus) only occupied six-tenths of the sky. Immediately after the start blue strips of sky—cloudless weather—could be observed eastwards over the fjords and the inland ice. Thus the bad weather had not penetrated very far into the fjords. It also became brighter in the south, in exact accordance with the morning's weather forecast. In spite of the strong winds encountered at first, there were no squalls worth mentioning, apart from a few short gusts which occurred at an altitude of 600 metres when flying over low mountains on the coast.

Upon arriving over the glacier which flows into the sea half way between Godthaab and Ivigtut, near Fredericshaab, the course was directed towards the inland ice. During the flight the temperature was measured continually, and these measurements showed that (and nothing else could be expected in cold water areas) over the surface of the water, up to an altitude of 300 metres, lay an inversion, and at a maximum height (2,000 metres) even over the inland ice margin, a temperature of $+5°C$ prevailed, that is to say, a difference of only 4° as compared with the temperature over the water. These relatively high temperatures were also due only to dynamic heating. The great dryness of the air indicated that there was a downward movement of the air. At an altitude of 1,500 metres, for instance, only 20 per cent. relative humidity was measured. For the same reason visibility was also extraordinarily good, at an altitude of 200 metres it amounted to about 300 kilometres. The whole of the outline of the coast of Cape Farewell was observed and appeared extraordinarily plastic, as on a topographical chart.

The return flight from Ivigtut to Godthaab was fixed for the following day, the 19th August. A start was made at Ivigtut at 10.30, and this time the flight followed the coast. Again there was found to be an inversion between water surface and 200 metres altitude, with a difference in temperature of $2\frac{1}{2}°$. Over the water 9.2°C., at 200 metres 11.6. On leaving the Arsuk Fjord, the temperature at the altitude of flight (200 metres) dropped to 9.1°C. This fall in the temperature may have been due to two causes: First the cooling action of the

cold water stream at the coast—owing to its low temperature—will be greater than that of the warmer water inside the fjord, also there is generally some air movement on the coast which is often lacking in narrow fjords such as the Arsuk Fjord. Thus the start was made in Ivigtut in a complete calm, in the almost stagnant air between the mountain slopes, this air being exposed merely to the influence of radiation. Therefore, here also the ground inversion was so pronounced.

This flight emphasised the fundamental difference between the climate of the fjord on one hand and that of the open coast on the other hand—in the first case the continental influence predominating and in the second case the maritime. This applies to the whole of the west coast of Greenland, and will be explained below.

In the stream moving northwards along the coast at this time there is very much ice, partly ice floes from the fjords on the west coast, and partly large icebergs driven round Cape Farewell. Over this cold surface ice mist had formed which was very thin at the exit of the fjord and did not impair vertical visibility. In the vicinity of the mouth of the fjord, there were only a few icebergs which were surrounded by a thin veil of mist. Further northwards, where the mist had become thicker, the tops of high icebergs protruded from the sea of mist. The height of the mist was approximately 50 metres, this height being probably determined by an inversion. To the south the sea of mist was boundless, while to the north and towards the sea a limit could be observed. This mist is therefore associated only with the coast, and is of no essential importance to the airman owing to its inconsiderable height, provided that only places in protected fjords are used as ports. Above Fredericshaab, the northerly limit of the mist was reached. The visibility aloft was excellent; at an altitude of 300 metres the high mountains of Godthaab could be seen 100 kilometres away. The range of vision in such atmospheric conditions is practically dependent only on the altitude of flight. In the west and north-west, the sky was covered with cirro-stratus and alto-stratus which belonged to the area of low pressure over the north of Davis Strait, while to the east, over the inland ice, the sky was quite cloudless (area of high pressure over the continent).

The second long reconnaissance flight to Lisko Bay had to be discontinued owing to a defect in the engine, and as the repairs took several days, the flight was abandoned. Several flights were however carried out in the neighbourhood of Godthaab, during which further experimental results were obtained. The ground inversion was still in evidence (Temperature over the water 6.7,° at 600 metres 9.0° C., and at a higher altitude the temperature was probably still higher). Such an inversion is associated with a non-vortical movement of the air in the lower layers, which movement is interrupted only over land and in the disturbed stable stratification between high mountains by sensitive gustiness, as clearly shown during one of these flights.

(5) *Flight Section: Greenland—Hudson Bay on the 28th August*

For preparation for the flight to America, weather charts were prepared twice a day on the basis of weather reports from America, Canada, Greenland, and oceanic reports.

In the whole of the area of Hudson Bay, no weather reports were available. From the immediate vicinity only Nottingham Island, Resolution Island and Cape Hopes reported their weather. It was important that barometric charts should be completed for this area as accurately as possible, in order to be able to draw conclusions as to the probable weather. On the 28th August the atmospheric conditions according to the morning chart, appeared to be favourable for a start.

South of Cape Farewell there was an area of low pressure which had not long ago left the American continent at Belle Isle, and was moving eastwards over the Atlantic. It was followed by a powerful wedge of high pressure, the

divergence line of which, at the time of crossing the American coast south of Newfoundland, was running in south-northerly direction over Labrador to the middle of the Hudson Strait. Over Baffin Land and Baffin Bay a fairly shallow area of low pressure was observed, whose loose connection with the above-mentioned Atlantic "low" was completely dissipated by the high pressure component developing to the east. Thus completely calm weather was to be expected over the Davis Strait. The main energy which brought about the eastward movement of this pressure formation emanated from a growing cyclone moving very rapidly to the sea region. Even in these circumstances it was not to be assumed that on the day in question the weather would deteriorate on the stretch Godthaab-Hudson Bay. From the isobaric chart based upon the few weather reports received, the following weather forecasts were obtained quite systematically:—Over the Davis Strait moderately strong N.W. winds, approximately strength No. 3, over mouth of Hudson Bay abating while veering to the west, on the coast of North Labrador almost calm (here the meeting with the divergence was presumed) and later land (Labrador) south to south-east winds, generally weak, but possibly—just before Hudson Bay coast, in consequence of the gradient strengthening of the approaching area of low pressure, freshening up to strength 3-4. First of all, the most important thing was the determination of the direction and strength of the wind, as it was necessary to make an uninterrupted flight of almost 1800 kilometres owing to the lack of suitable intermediate landing places. For far the greater part of the entire distance, however, contrary winds were to be expected, the strength of which, nevertheless, remained within certain limits which rendered flight possible. The postponement of the flight for a day was certainly contemplated, because it could be assumed that with further eastward movement of the wedge of high pressure, the zone of north-west winds would shrink considerably. However, it could not be decided with certainty if the American "low" would not then make its influence felt (Frost, mist, drizzle). It was however essential to avoid bad weather with limited visibility in the unknown and uninhabited regions between the mouth of the Hudson and Hudson Bay. Thus, on the 28th August, the atmospheric conditions over the whole stretch being good, it was decided to make a start. The weather reports received in the morning from Resolution Island and Cape Hopes (cloudy but good visibility) could be considered as favourable. It will not be necessary to describe the weather conditions during the flight as they agreed with the forecast. It may however be mentioned that visibility was remarkably good, particularly when half way through the journey. It must also be mentioned that owing to head winds the flight could not be made direct to Port Harrison (Hudson Bay) as had been planned, but a course was shaped towards Povungnituk, situated on the same coast but further to the north. Owing to approaching darkness, a landing was made in an Eskimo settlement in the immediate neighbourhood of Povungnituk.

On the following day, the 29th August, the journey from Povungnituk to Port Harrison was flown in 1½ hours. Now the area of low pressure was heralded by a freshening of the wind (No. 4), cloudiness increased rapidly with showers.

(6) *Flight Section: Port Harrison—Long Lac on the 31st August*

On the 30th August the weather was very bad and the start was postponed until the 31st August. The wind had already veered to N.W. (weather in the rear of a depression). At first the clouds hung down almost to the ground. The coast which was 300-400 metres high, and where stemming occurs with north west winds, naturally also had a bad effect. But as soon as the course was shaped more to the west, where the coast of the Hudson Bay projects to the west, the weather improved considerably. The rear of a depression accompanied by cloudy weather but good visibility, and with only a few showers, was passed through. Accordingly the strength of the wind decreased from N.W. 5 to N.W.2.

Start in Port Harrison: 11.35. Landing in Long Lake, 20.05.

(7) *Flight Section: Long Lake—Chicago*

The most interesting meteorological phenomenon observed during the flight was an extensive area of fog over which we flew. The presence of this fog was a matter of course under the prevailing atmospheric conditions. The precipitation which had fallen during the passage of the cyclone had increased the moisture content in the lower air layers to such an extent that on the rear side, night radiation caused it to turn to fog. That is a very frequent and normal process also with us, and differs very much quantitatively in various districts. The condition of the ground has a great deal to do with it.

Start at Long Lake, 12.05. Landing at Chicago 18.00

Some Contributions to the Aeronautical Meteorology of Greenland

The following statements are based substantially on the experiences gained during the Summer of 1931, as a result of meteorological observation in Greenland. This information was gained during a stay of several months on the west coast, which provided many opportunities for studying local atmospheric phenomena, and also during two sea voyages (outward and return voyage) which permitted a comprehensive survey of the influences of the continent of Greenland on the general atmospheric conditions over the North Atlantic. An extremely valuable supplementary experience was a journey along the coast to Upernivik (below 72.5° N. Lat.). During this trip a visit was paid to almost all of the places along the west coast, the most northerly trading centre of Greenland (below 75.5° N. Lat.) and a large number of interesting atmospheric observations of phenomena typical of the coast of Greenland were made. The main activity in Greenland was obtaining meteorological information for the Greenland flight. For this a knowledge of local weather was indispensable.

Generally speaking, two weather types may be singled out which give the weather on the west coast of Greenland its distinctive character. Namely—the area of high pressure due to continental thermal conditions, and the low pressure over the Davis Strait which in most cases is only in the form of a weak secondary depression or tongue of the cyclones passing over southwards from Cape Farewell. The direct influence of the areas of low pressure passing at the south of Greenland does not generally extend into the latitude north of Godthaab; it is rather tongues which, in conjunction with areas of low pressure, pass by the very much more northerly course *via* North Canada to Baffin Land, and there generally fill up. About 200 kilometres south of Godthaab there is the neutral zone which represents the boundary between the disturbances of the far north and the Atlantic. Slight variations in the strength of the continental " high " and also small differences in intensity in the low pressure over the Davis Strait, cause quite different atmospheric conditions on the west coast. In the case of winds with westerly components, the *fog* which is almost always present over the cold water of the Davis Strait, is driven to the coast and into the open fjords. Narrow fjords which are closed towards the sea by high mountains, are much more protected from this fog. Not only is the wind direction important, but also the strength of the wind. If the winds are only very weak, in certain circumstances, the heating of the coast caused by powerful insolation is sufficient to dissipate the fog immediately and to keep a strip of the coast (the breadth of which, however, varies) free from fog. The situation is quite different when winds of easterly components prevail. Föhn-like clearing-up sets in, the fog being driven out to sea, but even with these atmospheric conditions the fog remains in the form of grey streaks extending from the coast. In many cases the fog does not recede more than 500 metres to one kilometre from the coast, and remains in the same position all day. In such circumstances, in the face of the threatened fog, a forecast (whether influx of fog or not) is extremely difficult. All this applies mainly to the coast only; within the fjords there is no danger of sea-fog suddenly

appearing, which is a great advantage for air ports within the fjords. For this reason, Godthaab could hardly be used as a base for a regular air service. The other stations on the central and south-*west* coast suffer more or less from the same disadvantage. For this season, small places inside the fjords are preferable.

The *ice conditions* on the west coast of Greenland offer no direct obstacle to flying during the Summer (apart from the fogs). The fjords and also the coast are free from ice almost all through the year, so that the motor-boat service along the coast is hardly ever interrupted. With strong south-west winds however, it sometimes happens that quantities of drift ice are driven into the fjords and some of the ports, for instance Julianehaab, and these are either filled or blocked with ice. This happens much more rarely on the coast near Godthaab, as there the quantities of drift ice have already considerably decreased. The Godthaab district may be called an ice-free zone as the winter pack ice begins 400 kilometres north of Godthaab, in the Holsteinborg district and north thereof.

When disturbances approach the coast, the wind sometimes freshens up very suddenly owing to the high pressure gradient produced on the coast (as the area of high pressure over Greenland maintains its position) the temporary violent freshening up of the wind over the fjords is very marked. Frequently, far in the fjords strong down gusts have been observed which have been indicated by the cloud formation, and these gusts are such as would certainly be very dangerous for aeroplanes in the fjords.

An important question is, which route should be chosen for a flight from Iceland to Greenland in order to enjoy the most favourable meteorological conditions? The route via Scoresby Sound, which was selected mainly from scientific considerations for this year's Greenland flight, is too complicated from the meteorological point of view. The dangerous stretch from Scoresby Sound over the inland ice to the west coast, is too long. There are really only two routes to be compared, namely (1) Reykjavik-Angmagsalik, over the inland ice to the west coast, and (2) Reykjavik-Cape Farewell, to the west coast. Further, it must be decided if the port of destination should be more to the south, in the Julianehaab district, or further to the north towards Godthaab. In accordance with what has already been said, preference must be given to a port in the vicinity of Cape Farewell. The stretch of inland ice can then be avoided, and not only that, it very often happens that the atmospheric conditions on the east coast (Angmagsalik) and on the west coast (Godthaab) have exactly opposite weather conditions—either good weather in one and bad in the other, or vice-versa. This difficulty will not be experienced in the same measure on the route round Cape Farewell, as there we have an area of similar atmospheric phases.

PROCEEDINGS

TENTH MEETING, SECOND HALF, 67TH SESSION

A Joint Meeting of the Royal Aeronautical Society and the Guild of Air Pilots and Air Navigators of the British Empire was held in the Lecture Hall of the Royal Society of Arts, 18, John Street, Adelphi, London, W.C.2, on Thursday, May 5th, when a paper on " The Training of Pilots and Instructors," by Group Captain J. E. A. Baldwin, D.S.O., O.B.E., was read and discussed.

Mr. C. R. Fairey (President, Royal Aeronautical Society) was in the chair.

The CHAIRMAN: At a recent lecture to the Society, on the subject of accidents, it was stated that approximately 80 per cent. of the accidents in the R.A.F. were due to errors of judgment on the part of pilots, and it had been pointed out that, so far from deploring that figure, they should regard it from the point of view that when it rose to 100 per cent. it would imply that the aeroplane was perfect. That was a truism, but a very misleading one, because although the aeroplane might be perfect, the lives of those who flew them would not appear to be any safer than before that state of affairs was achieved. All of this bore on the very great importance of proper training. The training of the pilot became the most important item nowadays in connection with flying, either military or civil.

Introducing Group Captain Baldwin, the Chairman had no hesitation in describing him as one of the greatest authorities in the world on the training of pilots and instructors. He had only recently relinquished the command at the Central Flying School, and whilst one would wish to spare his blushes by refraining from giving too long an account of his distinguished career, it was well to remind the meeting that he was actually flying in 1911, that at the end of the War he was in command of the first Wing of the Independent Air Force, and that he was in command of the school that did the first initiative line flying.

TRAINING OF PILOTS AND INSTRUCTORS

BY

GROUP CAPTAIN J. E. A. BALDWIN, D.S.O., O.B.E., A.D.C.

1 Introduction

I wish to make it quite clear that any opinion expressed in this lecture is merely a personal opinion, and does not tend in any way to express the official view.

As a serving officer it has been necessary for me to obtain permission to give this lecture, and a copy of the proposed lecture has been submitted to the authorities, but this in no way implies that they are in agreement with the opinions expressed in the lecture.

The necessity for a standard method of instruction in flying cannot be over-emphasised and is, I submit, equally necessary in civil flying. The public cannot yet be said to be fully alive to the possibilities of aviation and therefore flying instruction and flying generally must be considered to be still in the development stage.

In any new venture in its development stage " safety first " is a factor of primary importance. Every year the number of miles flown steadily increases, and it is only natural that the total number of casualties should, to some extent,

increase. It is impossible to impress this on the public as the existing Air Lines and the number of hours flown are not nearly so easily impressed on the mind as, for example, the length of railway lines in existence, nor is the average pedestrian likely to notice the increase in the number of aircraft using the sky (unless he has the misfortune to live near an aerodrome) in the same way as he will actually notice the increase of motor transport on the roads. He is much more inclined to notice the total number of casualties given in the daily Press and to consider that flying remains as dangerous as ever. It is therefore obvious that the first essential to popularise flying is a really sound system of instruction in the art of flying.

In dealing with the evolution of flying instruction I have divided this into three periods:—

(*a*) The method employed in pre-Gosport times.
(*b*) The Gosport or Smith-Barry method.
(*c*) The present-day method.

2 *Early or pre-Gosport Instruction*

This really includes all instruction up to the summer of 1917. It was a period during which, to all intents and purposes, there was no true method of instruction, pupils being more or less self-taught. The novice was given experience as a passenger and in taxying his aircraft, *e.g.*, Bleriot-Penguin. After this the pupil was told to carry out a straight flight or hop, and when considered proficient on these was allowed to carry out a circuit. During this period of learning to fly by pre-Gosport method it is fortunate that only slow aircraft were employed. With the advent of the Maurice Farman, of the Long or Shorthorn type and the 50 Avro, dual control was introduced, and a pupil was, to some extent, given a smattering of instruction as to how the controls worked. Any pupil who could make five landings without interference from his instructor was allowed to go solo. He was taught practically nothing further and had to learn the rest himself. No such thing as advanced dual was given unless the pupil crashed.

3 *Gosport or Smith-Barry Method*

This system embodied the realisation that dual instruction with adequate communication between instructor and pupil was essential. In the words of Smith-Barry: "The chief thing necessary in flying instruction is dual control." Dual control has been employed to teach every manœuvre; flying in a wind, landing and getting off across wind, spinning, etc. The next most important thing is that quite half the dual is administered after the pupil has gone off solo, as until a pupil has himself practised a given thing he will not appreciate the details that are shown him. Bad habits are also corrected before they have had time to become fixed. This advanced dual, as it is now called, may be put down as the salient feature of the Smith-Barry system. Another innovation was that pupils were allowed to fly exactly as they chose and were not warned against doing certain evolutions which might land them in difficulties. They were encouraged to try out a manœuvre and when by incorrect use of the controls they got into difficulties, they were shown how to get out. This was the other great innovation; after being shown how to get out of a difficult and previously considered dangerous position, the pupil was sent up again to repeat the process alone, and in the words of Smith-Barry, if the pupil considers this dangerous let him find some other occupation; in other words, a person cannot be taught to fly by merely being taught to avoid doing certain movements. Another great difference was that instructors now taught pupils from the passenger's seat and pupils had not the embarrassing change of seat before the first solo. I think it is correct to state that the demands of air fighting can be regarded as directly

responsible for bringing about this change in flying instruction. No pilot could fight his aircraft if during the whole of the training period he had been taught nothing but how to avoid doing certain movements.

4 *Present-Day Method*

The present-day method can be said to be a mere elaboration of the Smith-Barry system. It is a comprehensive and progressive method of instruction in the air, embracing all manœuvres which are of practical value. Efficient telephone communication is regarded as of primary importance together with numerous periods of advanced dual in which careful supervision is given to the individual's flying after the solo stage is reached. This system is worked through a sound and logical sequence of flying instruction which is, however, sufficiently elastic to be made adaptable to the different temperaments of instructors and pupils, and is assisted by careful selection of intelligent and thoroughly trained instructors; this latter condition being most important.

5 *Selection of Instructors*

In dealing with the system of instruction I propose to deal chiefly with the method by which a pilot is taught to become a flying instructor. If this is followed closely it will automatically cover the ground of "Ab initio" flying training. Before commencing training as an instructor an individual must possess certain very necessary qualifications, of which I am inclined to place temperament as the most important. By no means can every good pilot be considered as likely to make a good instructor. A pupil must have complete confidence in his instructor and must retain such confidence. An instructor must therefore be a pilot with a complete and accurate knowledge of flying and airmanship and the ability to perform automatically any flying manœuvre, added to which he must possess the power of explaining his subject in detail, and be blessed with considerable patience. Unsuitable temperaments and clumsy flying are of no use. Here arises one great difficulty; a good pilot must have a quick reaction and be able to carry out manœuvres automatically. If he is to be a good instructor, he must be able to analyse these manœuvres and synchronise his explanations to his actions when demonstrating. Experience has shown that pilots of experience find this a real difficulty. The careful selection of individuals as instructors is one of the most outstanding features of the present-day system. In fact this and the improvement in the good communication between instructor and pupil and the stress placed on the necessity for the instructor synchronising demonstration and speech, are approximately the only embellishments on the Smith-Barry system. The old idea that a good pilot automatically proves to be a good instructor is definitely dead.

6 *The System of Instruction*

The necessity for a standard sequence of instruction, particularly for military purposes, is that it permits a change of instructor without loss of continuity of instruction, eliminates any haphazard methods, produces a finished pilot known to possess certain knowledge and to have passed certain tests. Whilst the system of instruction is thus standardised, giving continuity if an instructor is changed (although any change in the early part of the instruction is to be deprecated), the instructor must adapt this system to suit his own temperament and the individual characteristics of his pupils, and also to the type of aircraft that he is using. A great asset in flying is mobility and the method of instruction must also remain mobile and flexible to suit individual characteristics. It must, in addition, be kept up to date to suit any change in type of aircraft or change of methods of control, *i.e.*, friezed ailerons and slots. The word "patter," which describes the printed form of the Central Flying School syllabus,

is unfortunate as it conveys the idea that the method can be learned parrot-fashion and this is the very thing to be avoided. In fact it was noticed that instructors were liable to attempt to become word perfect in the " patter," so now the " patter " is not issued to individuals until they have completed their course. Each individual is now instructed in the whole syllabus which he puts into his own words when carrying out demonstrations and is only issued with his copy of the " patter " when he leaves. This copy is issued to him so that he can refer to it to ensure that he is keeping on the right lines, and also endeavour to find out any method whereby it may be improved.

7 *Instructors' Course*

The actual instructors' course at the Central Flying School is of eleven weeks' duration. This might be considered unnecessarily lengthy, but it gives the staff the opportunity to study the individual and for the individual to really absorb the necessary material. Synchronisation of speech with demonstration alone takes time; especially to do the movements slowly in order to fit in an adequate explanation to the demonstration. It must be remembered that the embryo flying instructor must be taught exactly as if he was an " ab initio " pupil, *i.e.*, before being considered fit to go solo he must be taught:—

(i) How to handle the engine, which in these days is of comparatively high power and as yet by no means foolproof.
(ii) To handle aircraft on the ground with safety to personnel and other aircraft.
(iii) To fly straight, change direction, get off the ground, back on to it, and, if necessary, recovering quickly from a spin, and deal with any situation which may arise from engine failure.

All the above is considered primary dual instruction, and at the end of this stage the flying pupil can fly and may be ready to commence solo flying practice. Unfortunately, in many schools, due to reasons to be touched upon later, this is where flying instruction ends. In the subsequent stages the pupil must be given finish in the elementary flying and instructed in the more complicated combined manœuvres, such as gaining height during change of direction, side-slipping and losing height without a gain in forward speed, taking-off and landing across wind—the style of approach which will enable him to land exactly where he wishes, without relying on the engine—cross-country flying and sufficient knowledge and experience to handle aircraft in unfavourable weather conditions. Also a more thorough knowledge of the functions of the controls and aerobatics. Here the necessity for a system becomes apparent as otherwise there would always be the danger of the instructor giving an undue proportion of instruction in the subject in which he himself is most interested, such as an unnecessary amount of instruction in aerobatics whilst neglecting instruction in gliding, turns and approaches.

8 *Detail of System*

The selection and training of an instructor is very important if really sound instruction in flying is to be obtained and I feel that a somewhat detailed description of the system now in force for producing service instructors is necessary.

The day is divided into three parts:—

(i) Flying with the staff instructor.
(ii) Ground lectures and workshops.
(iii) Two embryo instructors practising together.

The pupil is taken in the air by the staff instructor in a dual control aircraft fitted with efficient telephones. The pupil occupies the instructor's seat and the staff pilot the pupil's seat. On the first flight the staff pilot checks over the

pupil's flying, this has to be done unobtrusively. Pilots of experience frequently develop bad style and bad habits and these have to be entirely eliminated if the pilot is to become an instructor. On the second flight practical training in instruction begins. The sequence of instruction is divided into a number of lessons. The would-be instructors are given exactly the same lessons that they will subsequently give their pupils and in the proper sequence. Each lesson is complete in detail, including the diagnosis and correction of faults. During the lesson the staff instructor describes each movement of the aircraft or engine controls whilst he actually makes it and points out the effect of the movement on the aircraft, giving the reasons for making it. In some cases the demonstrations are exaggerated to make them more marked, but are never faked. At the conclusion of the demonstration the staff pilot hands over control to the pupil, who has to repeat the lesson making his explanation coincide with the demonstration, but using his own words. He is definitely cautioned about attempting to commit anything to memory. The correct method of giving a useful demonstration is to describe exactly what is happening. Any attempt to commit wording to memory usually leads to a species of patter which does not necessarily coincide with the demonstration being given. Preliminary lessons in the air are confined to the use of the controls separately; during this period the pupil learns to speak correctly into the telephone, analyse the effect of control movement, and begins to appreciate the " ab initio " pupil's point of view. The next period is the use of controls in combination—straight flying, climbing, gliding, taking-off, landing, and turns—exactly the same system of explanation and demonstration coinciding being used. During this period the diagnosis and correction of faults come into consideration. When the pupil has mastered the description and demonstration of the complicated use of controls in a turn he has overcome one of his main difficulties of grasping the principles of analysing his flying. From this time he really begins to think for himself and everything is far more easy and natural for him. Next period consists of preparation for solo spinning, elementary forced landings, and low flying, and finally a lesson on testing a pupil before his first solo. By this time the instructor's own flying is automatically showing signs of increased accuracy. It will be rather a studied accuracy, but he will not be far from perfect in this respect. The following lessons are devoted to advanced dual after the pupil has done his first solo.

The would-be instructor is here taught to explain the use of the controls in the more complicated movements, and this is the period during which he himself learns style.

Each period of instruction occupies approximately 35 minutes. During this time two items of the sequence can be practised, it is not satisfactory to endeavour to cram the instruction. Having had a lesson in the morning the pupil is given a rest from flying until the afternoon, when two pupils are sent up together to practise what they have learnt in the morning. In the meantime they are occupied with the ground syllabus.

9 *Comments on System*

This very roughly sketches the sequence of instruction. This has been evolved as the result of the experience gained since the foundation of the system in Gosport times. There is always the tendency (usually after an accident) for suggestions to be put forward which would necessitate the inclusion of too many items before the first solo. This should be resisted. Any increase in the present number of items is likely to prolong unduly the amount of dual before solo and re-act on the pupil's confidence. The system provides for a thorough instruction in all the essentials before a pupil goes solo and for a continual return to dual to correct any faults afterwards; in addition to teaching the more difficult manœuvres such as taking-off and landing across wind. No exaggerated importance is attached to teaching aerobatics, more effort being centred on teaching

the pupil to become a steady, accurate and reliable pilot. In the specialist training of instructors attention is paid to the teaching of aerobatics, as one of the first qualifications of a good instructor is that he must be a highly skilled pilot and a complete master of his aircraft. Special attention is given to spinning, but spinning is not classed as an aerobatic. It is a normal training manœuvre. Pilots under training are given a considerable amount of spinning practice in order to get them accustomed to the sensation. Whilst admitting that most modern aircraft are reluctant to spin the object of this training in spinning is to so impress the method of recovery on the pupil's mind, that the correct control movements become automatic to him. With the reliability of modern engines it may be suggested that the time given to forced landing practice is somewhat excessive and will seldom if ever be needed. Against this it is to be remembered that when needed there is no time to be wasted in thinking out the best method. As in spinning, the correct method must be impressed on the mind by constant practice until it becomes automatic. Before leaving the detail of instruction I should like again to impress the necessity of frequent return to dual instruction and, in order to obtain the best results from dual instruction, good telephonic communication between instructor and pupil. The instructor should never interfere with the pupil's flying except as a last resource, but should merely inform him what he is doing wrong and what it is necessary to do to correct this. I should like to quote Smith-Barry again on this subject: Dual instruction can only be effective if the pupil constantly realises that he has complete control of the aircraft. Whenever the pupil is practising any evolution the instructor should not touch the controls until absolutely necessary, and must show the pupil that he is not touching them. The length of dual instruction necessary to teach a pupil any particular manœuvre will be very considerably cut down if this procedure is properly observed and the aircraft controlled by the pupil acting on the direction of the instructor given over the telephone. It is important that this procedure be maintained even when the pupil gets into difficulties, for it is particularly at such times that the sound of the instructor's voice giving clear directions will do more than anything else to develop the pupil's confidence and make him feel at home in the air.

10 Civil Flying Instruction

Whilst many of the schools and clubs give very thorough instruction on the lines indicated, the majority are handicapped by

> Firstly, the fact that dual instruction is paid for by the hour; and
> Secondly, with a small establishment of aircraft, the serious consequence which damage to the aircraft entails.

The latter results in a certain amount of safety first methods being employed, and the former has often even more serious consequences. Under the hourly rate the pupil wishes to go solo as soon as possible to save expense (perhaps the club also has its subsidy in mind for the extra pilot's ticket), and after having gone solo many pupils take little or no advanced dual. The result is that faults arise which are not corrected and many important parts of the training, such as advanced forced landings, cross wind landings, etc., are omitted.

11 Results of the System

On completion of a flying instructor's course pilots may be considered to be satisfactory instructors; most are really very good. Actual experience with pupils increases this ability and it is no longer necessary for him to learn how to instruct by bitter experience and failure with pupils. Instructors must be encouraged to air their views. By describing their difficulties they draw attention to possibly weak points in the training system. It is in order to do this and to ensure that the standard system is not suffering variations that the staff of the Central Flying

School visit all other training establishments annually. To illustrate the very real need that there is of a sound system of instruction I would like to quote some figures and which I think will illustrate how expensive the old method proved itself to be.

> During the period 1914-18 there were issued to the R.F.C. and R.A.F. (exclusive of the R.N.A.S.) no less than 39,592 aircraft. Of these 18,279 were issued for training purposes.

Now with the present system of instruction aircraft at training establishments are completing their 1,000 hours.

In peace time the necessity for safety first and in war time the necessity for avoiding wastage of aircraft and personnel and of concentrating the maximum production to replace the normal war wastage, both demand a sound system of instruction. I would suggest that a civil school for flying instructors on similar lines to the Central Flying School and with power to award categories, thus preventing the employment of inefficient or unsuitable individuals, is now necessary.

12 Instrument Flying

I have not touched on instrument flying as this is still in its primary development stage in so far as this country is concerned. We were slow to recognise the necessity for this, although a start was made in instrument flying in 1918. Further research was allowed to lapse and this branch of flying was only seriously taken up about 18 months ago. The present tendency is to regard it as an entirely separate method of flying as distinct from what might be called sensory flying. The more experienced a pilot is the more difficult it has been found to persuade him to fly entirely by instruments. At the present moment apart from a complicated system of wireless beams there is no accurate method of informing a pilot as to his height above the ground when flying in fog. Otherwise the instruments as they exist to-day enable a pilot after approximately ten hours' tuition to fly accurately although he is bereft of all vision.

Instrument flying is a process of unlearning, as much as learning, and involves imposing definitely unpleasant sensations and reactions on the pupil.

A Definition of Instrument Flying.—Instrument flying is a method of controlling an aircraft, in which normal sense reactions are replaced by those determined by instrument indications.

Instrument flying may be said to consist of two methods:—

(i) Mechanical.
(ii) Human agency.

A pilot must, however, be able to check the automatic pilot and to take over control when necessary. He must, therefore, know how to fly by instruments. The automatic pilot is most suitable for large type aircraft and long distances, as it relieves the pilot of fatigue and strain.

The Object of Instrument Flying.—The object of cultivating instrument flying may be stated to be as follows:—

(*a*) It is essential for flying in circumstances of nil visibility.

(*b*) It enhances safety in circumstances of poor visibility, such as night flying, conditions of heavy haze, and increases the ability of a pilot to fly accurately by compass.

(*c*) It ensures that, if control is lost through any cause, it can be regained with a minimum risk in conditions of blindness.

(*d*) It is a more easily acquired craft than its counterpart, which may be called sensory flying. Therefore, training could be made cheap and rapid, and less careful selection should be necessary.

(*e*) It is of great value in any circumstances where a very high degree of accuracy in flight is required, *e.g.*, photography, wind finding and experimental flying.

(*f*) To have acquired skill in instrument flying is to have an enhanced morale in the ordinary duties of a pilot.

It would appear possible to train personnel to fly by instruments who would not be capable of flying accurately by sensory methods. Thus the whole crew of a large aircraft may be called on to fly on cross-country flights, and the duties of the responsible pilot would be rendered less onerous and he could remain fresh to exercise his wider skill in circumstances more deserving of it, *e.g.*, the actual landing.

Senses Used in Normal Flying.—The senses used in normal flying are:—

(i) Sight.
(ii) Hearing.
(iii) Feel.
(iv) Sense of balance or sense of acceleration.

(i) and (ii) are reliable, but (iii) and (iv) are unreliable and definitely misleading, unless used in conjunction with sight.

The pupil must learn, therefore, to handle his controls in sympathy with the instruments and to ignore ordinary (or it may be extraordinary) physical sensations in favour of purely mechanical information. This latter is by far the hardest faculty to acquire. Although, perhaps, a dangerous generalisation, the impression is given that, the more experienced a pilot is, the more difficult he finds this portion of instrument flying.

Ambiguous sensory conditions always result in the wrong reaction from the pilot, *e.g.*, the pilot receives a sense of sideslip and immediately corrects for wing down, whereas the sideslip is, in fact, a skid due to yawing.

Practically every error—certainly every serious error—is set up primarily by a yaw.

The controls, in order of difficulty of management, are:—

Rudder.
Elevator.
Aileron.

Fatigue is one of the chief difficulties in learning instrument flying, although pupils will not admit this and, in fact, fail to realise it.

The system of teaching instrument flying is as follows:—

(i) Experience of the instruments in open cockpit.
(ii) Dual instruction and practice under the hood and in cloud.
(iii) Lectures.

The instruments used consist of:—

Compass.
Turn and bank indicator.
Air speed indicator, supplemented by a
Pitch indicator to show attitude.

Turns.—Flat turns are taught, as these are easier, due to the air speed remaining constant, and also this type of turn suits the present instrument used, as the needles have only to be kept in one straight line. Also this type of turn suits the compass.

Taking Off.—First, the use of the rudder alone is taught, then all the controls. The stick is held neutral and the general flying instruction includes recovery from any manœuvre.

Spins.—Spins, and the recovery therefrom, are given special attention, as this is most difficult to learn, and spin recovery has two values:—

(i) It assures the pupil of the possibilities of recovery in emergency.
(ii) It entails the most complete detachment from mental and physical reactions, as the angular distances in recovery are of a higher order.

Finally, the endurance test of a cross-country flight of at least one hour's duration, is undertaken. The conclusion arrived at is that the art of instrument flying is easily acquired and does much to raise the morale of a pilot when flying in difficult weather conditions and, although the automatic pilot is becoming very reliable, the control of the aircraft must primarily remain the pilot's responsibility and, therefore, he must be capable of instrument flying.

This instrument flying opens up an entirely new system of flying training. Are we to continue sensory flying by the methods I have outlined above, or are we to teach pilots to fly entirely by instruments in future?

13 Characteristics of Ideal Training Aircraft

The ideal training aircraft is one that reproduces to a marked degree all the characteristics of the modern high powered service type thereby rendering any intermediate training type unnecessary.

It must, however, be sufficiently light to be capable of being handled by one man when on the ground. It is essential that any training aircraft should be entirely free from any vice. It is further suggested that the tandem method of seating with the pupil in front, provided adequate telephonic communication is ensured, is better than the side-by-side system—blindness on one side in a congested area. The following are what I consider to be essential assets of training aircraft:—

(*a*) *Taxying.*—Must be fully controlled on the ground in all weather, tailskid or wheel controlled by rudder bar.

(*b*) *Controllability.*—Controls must be light, progressive and powerful. All three in harmony. Ailerons to retain control nearly up to stalling point and then to give definite warning of a stall.

(*c*) *Stall.*—To stall at a low speed, *i.e.*, approx. 40 m.p.h., and recovery effected with small loss of height.

(*d*) *Take-off.*—Get off reasonably quickly with two up.

(*e*) *Landing.*—Not too easy, requires feel before it can be landed really well.

(*f*) *Gliding.*—Angle of glide comparatively flat affording ample time for practising gliding turns, and resembling the angle of glide of the average modern aircraft. Not easily stalled on a gliding turn.

(*g*) *Spinning.*—Should show reluctance to spin except when deliberately stalled and full rudder applied, and recover readily when correct action is taken without excessive loss of height.

(*h*) *Side-slipping.*—Capable of being side-slipped in the normal manner.

(*i*) *Take-off and Landing Across Wind.*—Undercarriage neither too wide nor too low to allow for a relatively steep inclination of wings on the ground for taking-off or landing across wind.

(*j*) *Aerobatics.*—Has the necessary performance, strength, and flying qualities to carry out all normal aerobatics when flown by a pupil.

(*k*) *Visibility.*—Should be excellent in all directions. Top plane must not unduly interfere with the range of vision from the front cockpit.

(*l*) *Position.*—Both cockpits close together. The normal pilot's position to correspond with that in the modern service aircraft.

(*m*) *Entry and Exit.*—Front cockpit not to be directly under the centre section. The entry and exit to both cockpits to be unobstructed by struts or wires.

(*n*) *Maintenance.*—Ease of maintenance is an essential. Good clear access to controls by methods such as removable panels covering the sides of both cockpits. Sufficient space between engine and bulkhead to allow repairs and replacements to magnetos, oil pipes, etc.

(*o*) *Comfort.*—Both seats adjustable by hand-levers for height. Harness anchored to fuselage and not to seat so that it may be adjusted for aerobatics by merely heightening the seat. Rudder bar adjustable for distance by hand-operated wheel. Sufficient padding in front of cockpit to minimise risk of head injuries, carefully designed wind screens to reduce draughts to a minimum. All instruments on dashboard clearly visible.

(*p*) *Fuel Capacity.*—Fuel capacity of at least three hours, so as to avoid unnecessary refuelling.

(*q*) *Performance.*—Adequate climb to prevent loss of time between lessons or manœuvres and possessing a top speed of not less than 110 m.p.h.

(*r*) *Ballast.*—Tail adjustment by wheel, range large enough to allow aircraft to be flown solo from front cockpit without ballast.

(*s*) *Undercarriage.*—Capable of withstanding heavy shocks, but sufficiently resilient to show up bad landings.

Discussion

Mr. Gordon England (*F.R.Ae.S., Member of Council*): He expressed the indebtedness of his Company, the National Flying Services, and of other civil aviation companies, to Group Captain Baldwin for the enormous amount of help and encouragement he had given them from time to time. It was felt very definitely in his organisation that the Central Flying School methods were very suitable for civil aviation instruction. Whether or not that would always remain so was definitely debatable, because it was quite possible that if a large number of " the men in the street " were persuaded to listen to such a lecture as Group Captain Baldwin had given, they would say, " No flying for us; it is far too much like hard work." One would be very sorry if such an impression got about amongst civilians. At the same time, Mr. Gordon England considered such training as had been described to be absolutely necessary under present-day conditions, because it was fair to say that the modern aircraft was not suitable for the man in the street.

Another reason why he was glad of the privilege of opening the discussion was that he had had the pleasure, the anxiety, and sometimes the despair of having to teach Mr. Smith-Barry to fly. Any who happened to know that gentleman would appreciate that every one of the emotions referred to were likely to arise. In those early days, those engaged in commercial aviation were very greatly concerned to keep their aircraft intact; being commercial organisations, their anxiety had been to get their pupils through, for the high fees they used to charge then, in the minimum time and in the hope of making some profit. They had adopted the course, condemned by Group Captain Baldwin, of trying to prevent them doing certain things, but Mr. Smith-Barry had taken a fiendish delight in breaking every instructor's regulations and putting their hearts in their mouths most of the time he was up in an old box kite by doing what he was specifically told he must not do. Then, when he had landed, he would irritate, and tease them unmercifully by pretending not to understand why they should be at all concerned. Probably, if all the instructors who had had anything to do with Mr. Smith-Barry in the old days had been asked whether he had any future in aviation or was likely to inaugurate what had become really the world's standard

of training, they would have said emphatically, " No." That indicated how very wrong one could be about anything new that was being tried out. Mr. Smith-Barry, when he was really serious, would explain at great length exactly what his ideas were, and he was even at that time creating the fundamentals of what afterwards had become the Gosport course.

Mr. Gordon England asked the author whether he had considered the use of gliders and sailplanes for training. One of his reasons for asking the question was that a surprisingly high percentage of pilots, when they first performed on gliders, would " muff " it very badly. Another reason was that it would enable an extraordinary saving to be effected in the cost of instruction, because one could build quite a lot of gliders or sailplanes for the cost of one complete aircraft. He threw out for consideration the possibility of using an aerial " tug " to take, say, half a dozen of these dual instruction gliders to a height of 10,000 or 15,000ft., and releasing them there. This system would have the advantage of safety, and he believed pilots so trained would be far more alert than they were likely to be under present conditions. In his view, under present conditions they placed far too great a reliance upon the power of the motor to pull them out of most difficulties, whereas, if gliders were used, the pilots would become instinctively more resourceful, alert and light-handed and adaptable to difficult circumstances when encountered.

Mr. GRIFFITH BREWER (*Vice-President*): He recalled that in 1908 and 1909, when Wilbur Wright came to France, he taught all his pupils by means of dual control; he had sat at the centre of gravity of the machine, so that later on, when the pupil was able to fly alone, Wilbur Wright could leave the machine without disturbing its balance. That system was employed for teaching three pilots in France, three in Germany and three in Italy. Orville Wright had carried on the same system of instruction in America. Mr. Griffith Brewer added that in 1914, when at the Wright Flying School in America, he had passed through the same course, sometimes with Mr. Orville Wright and sometimes with an instructor of the name of Reinhardt. After about 100 flights round the aerodrome with the instructor, he was launched out alone, and had performed figures of eight and had passed his great altitude test of 300ft. That sounded very little to-day, but nearly all his instruction had been given at a height of only 20 or 30ft., so that sometimes the end of the wing seemed almost to touch the grass. It was rather scaring to anyone who came from the European schools, where they were taught in the manner described by Group Captain Baldwin. On the machines used, there were wind vanes, pieces of string tied to the front frame. The only instrument was an incidence indicator which the pupil watched rather carefully; it had a red mark on each side of a scale, and one had to be very careful to keep the pointer between those two marks.

Flight Lieutenant JENKINS: It was agreed that training in instrument flying involved a technique in training which was directly opposed to normal sensory methods. In his opinion, this did not mean that it would be necessary to standardise on one form of instruction for both purposes. It was his view that training in instrument flying would always require a special technique involving the use of methods differing widely from those employed in ordinary flying training.

Mr. S. SCOTT HALL (*A.F.R.Ae.S.*): He would like to refer to one or two matters on behalf of the Chief Technical Officer at Martlesham Heath, who regretted that he was unable to attend the meeting. The first point concerned the author's statement that ideal training aircraft should possess all the characteristics of the modern high power service type, and the further statement that it should, at the same time, be sufficiently light to be capable of being handled by one man when on the ground. Various other requirements were stated in the paper, which suggested a typical light aircraft. One would imagine that it was

impossible for a really light aircraft to possess the characteristics of the heavier service types, and he asked if it would not be better to have one machine for the initial stages of training, and then other machines more on the lines of the types actually in service, for the more advanced stages. He believed it was true to say that one could convert single-seater high-performance aircraft into two-seater aircraft with very little change in characteristics, so far as flying was concerned, and it seemed that that would be the more suitable type upon which to train a pilot for high-performance flying.

The author had stated, in regard to controllability, that ailerons should retain control nearly up to stalling point and then give definite warning of a stall. It would be interesting if that statement were enlarged upon. Did the author mean that an aircraft should give an indication of the stall by dropping a wing sharply, or did he merely refer to sogginess of lateral control with no vicious lateral characteristics? Again, with regard to aerobatics, the author had stated that an aircraft should have the necessary performance, strength and flying qualities to carry out all normal aerobatics when flown by a pupil. A pupil, said Mr. Scott Hall, would certainly impose higher stresses on an aircraft when learning aerobatics than would a skilled pilot, so that if one were to provide the same factor of safety in each case it meant that the aircraft used by the pupil must be definitely heavier than one used by the more skilled pilot.

Some amplification of the requirements the author had asked for in regard to performance would also be useful. In testing and choosing training aircraft one was up against two conflicting factors. One was that of strength, *i.e.*, weight, bearing in mind the rough flying and bad landings to which they would be subjected. Against that there was the factor of performance. Those two were in opposition, and it would be interesting to know what performance the author considered necessary. He had simply specified a top speed of not less than 110 m.p.h., and a minimum of 40 m.p.h., and good climbing characteristics.

As to the suggestion that a civil flying school should be formed for the training of flying instructors on lines similar to those followed at the Central Flying School, Mr. Scott Hall asked if there were not already a school in existence at Hamble which met that requirement.

In connection with instrument flying, the author had classified the controls in their order of difficulty as, (1) rudder, (2) elevator, and (3) ailerons, and then had stated that the instrument used, for blind flying was usually a turn and bank indicator. Surely, however, bearing in mind the order of difficulty of those three controls, and also the relative stabilities of most aircraft, one would suggest a turn and pitch indicator as the most suitable instrument.

Finally, referring to training by gliding, he said he believed that in Germany there had been developed a method of blind flying in cloud on sailplanes on which the airspeed indicator alone in conjunction with the rudder was used. If a pilot found he was turning he would use the rudder first to one side and then to the other, and according to whether the speed was increased or decreased, so he could correct and maintain a straight course.

Captain BRIE (Autogiro Company): The opinions of the author on one or two matters were rather opposed to his own. For instance, the author had stated that he considered the latest order about " S " turning was detrimental, *i.e.*, if one came in, on any form of aircraft, one was not allowed to " S " turn in order to keep the landing point in view. Captain Brie would be only too pleased to show anyone exactly how easy and simple it was to keep the landing point in view the whole time. There was no need to watch the airspeed indicator, for there was no fear of stalling.

With regard to the indication of what was happening to a machine under various conditions, he emphasised that the rotor of an autogiro gave that indication automatically. On a turn, the loading on the machine increased and the

stalling speed increased; under such conditions the rotor would automatically speed up. Under certain conditions there would be a loss of a certain number of revolutions on the rotor, and it was really most entertaining and instructive to watch so simple an instrument. The rotor indication on the autogiro was definitely a translation of what the machine was doing.

Mr. H. G. TRAVERS (London Aeroplane Club): He disagreed with the author's view that there was no difference between training for Service and civilian flying, and said that the two were as different as chalk from cheese. Service pilots were trained from the beginning with parachutes, so that they gained a parachute mentality, and that enabled them to carry through the advanced inverted training; the ultimate stage for the civil pilot was the instrument flying. Another point to be borne in mind was that those who were trained to become Service pilots were all young men, selected for their intelligence and physical fitness; they were under permanent discipline, they had to turn out in the morning as instructed, and they could be dispensed with if considered undesirable. Those responsible for instruction had not to meet competition and had not to meet the shareholders. The C.F.S. system was very excellent and very lengthy, but time was no object and money was no object. They could buy expensive aircraft and could break them. He had acquired by stealth a copy of the sequence of instruction and blind flying hints, and had adapted the methods to civil needs. There was no need to treat instrument or blind flying as something to be learned entirely separately. If one gave the pupils one control at a time (for example, if one gave them the rudder first when on the ground, and then gave them the rudder when in the air), one could teach them a great deal, and they would also learn to judge their height from the ground. They could be taught to fly by instrument just as they could fly in the open sky.

Mr. Travers suggested that if the Central Flying School wished to help civil aviation, and not merely establish another Government authority, perhaps they would allow those concerned with civil aviation to visit the school more frequently. With regard to " A " licences, he suggested that if the Air Ministry revised the whole licence system and issued no " A " licences except on the production of a log book, in which every hour of dual was signed for by a licensed instructor, and insisted on eight hours dual and ten hours solo, they would help to turn out a better civil pilot.

Flight Lieutenant JOHNSON: He expressed doubt as to whether the necessity for dual instruction in low flying was sufficiently brought out. He had made a rough calculation as to what period of time a Service pilot, who had done 250 hours' solo flying, had spent within 200ft. of the ground, this latter being the dangerous height, and it appeared that on the average of that 250 hours only 4 hours and 15 minutes would be spent at the dangerous height. That was insufficient to give a pilot any real knowledge of what was going on, and dual instruction at heights up to 200ft. should be accentuated.

With regard to non-Service pupils, he suggested that they should be made (as a condition precedent to " going solo ") to undertake to accept further secondary dual after they had experienced solo flying.

Discussing characteristics of aircraft to be used for instruction purposes, he suggested that it was very desirable that air brakes should be absolutely standardised on instruction types, because their use might so change the gliding characteristics of the aeroplane that almost any type of aircraft could be represented, and differences of load in any one aircraft could be represented by means of the air brakes. Obviously, if a pupil were in the habit of landing short, the instructor had merely to put the brakes on slightly, and the pupil would then understand the position definitely. He considered that a change of types of aircraft was important. Clubs were limited, of course, by the extent of their equipment, but it seemed to him that the more types of aircraft that the pupil was able

to handle, the better; it was very much more profitable to fly for 15 hours, that period being divided between three types of aeroplane, than to fly for even 50 hours on only one type.

Flight Lieutenant M. FINDLAY (Chief Instructor, National Flying Services): He felt that the system of instruction recognised by the Central Flying School in the Air Service was ideally suited to civilian flying. There was a slight difference between civil instruction and Service instruction, in that the former was paid for by the pupils themselves, and the pupils included people who would probably be medically unfit for the Service; but at the same time, the Central Flying School system, perhaps spread over a little longer period, and applied with patience by the instructor, was ideally suited to civilian instruction. The biggest trouble was in the selection of instructors. It did not follow that, because a man was an extraordinarily brilliant pilot, he was necessarily a brilliant instructor. An instructor must be able to impart knowledge in such a way as to give his pupils confidence not only in their instructor, but in themselves also; he must be interested not only in flying, but also in instruction, so as to develop in his pupils the keenness which was so essential to make good pilots; he must be able to perform any manœuvre that the aircraft could be made to perform; he must be able to " aerobat " as well as to perform ordinary straight and level flying, and at the same time explain the theory of any manœuvre; he must be gentle with his pupils, must refrain from correcting them harshly when they made a fault, and must allow them to carry their faults to a logical conclusion, consistent, of course, with safety; then he must correct them, explain how to avoid them, and how to carry out properly the manœuvre intended. Explanation combined with demonstration is essential. There was a great opening for good instructors, but it was practically impossible to find them; the system developed by the Central Flying School was most essential, and the sooner it was applied to civilian flying instruction the sooner the standard of civilian instruction will reach a standard that will be comparable with that already existing in the Service.

Mr. JOHN BELL: With regard to paragraph 10, dealing with civil flying instruction, he would like to add a few words based on close study since the formation of the light aeroplane clubs.

The payment of subsidy for new pilots has resulted in many pupils being put forward for their tests before they were really ready. Having obtained licences with little or no difficulty, pilots have found themselves in situations for which they have had no preparation, and the result has been a very costly way of learning what takes place in certain circumstances.

There is also that class of individual who will not take secondary dual on the grounds that he does not need it. There are also cases (happily few) of pilots who obtained their wings during the war and have since qualified for an " A " licence, refusing to allow an instructor to discover how really limited is their knowledge, simply because they have told the world at large how great is their prowess in handling aircraft.

These cases are in contrast with that of a pupil who flatly refused to go solo on the grounds that he was not sufficiently experienced. When at last the instructor persuaded him that he was sufficiently qualified, his flying showed a marked superiority over that of many pilots of two and three years' standing. Incidentally, this pupil roused the ire of the club committee because he was not bringing in the subsidy, and it was even suggested that he should be prevented from flying.

Flight Lieutenant R. C. PRESTON: He believed that the last occasion on which a paper on this subject was read before the Society was on January 24th, 1917, when the late Sir Sefton Brancker, then Director of Air Organisation at the War Office, had delivered a paper, entitled " Training the Military Flyer." In that paper, read 15 years ago, the author had stated:—

" Before the war, flying was comparatively difficult, and was the chief factor in the pilot's training, military qualifications being considered of quite secondary importance. Now, flying up to a certain standard is extraordinarily easy, but the standard of military qualifications required is getting higher and higher, and more difficult to attain, and at the same time the quality of flying demanded is growing every day. So our task at home grows harder."

Those remarks, said Captain Preston, still held, except that the " certain standard " was not quite so easily attained as Sir Sefton Brancker had thought. It was this standard, no doubt, that Group Captain Baldwin's paper was set to improve. The title of the paper was " Training of Pilots and Instructors," and whilst agreeing that it was a most excellent and interesting paper, Captain Preston felt that the two, as applied to civilian pilots, were, if not poles apart, at least on a different plane. He agreed most assuredly with the author's statement that a civil instructors' school, with categories, should be founded, as only by some such means could the quality be maintained. He ventured to think that even the Central Flying School had been sometimes placed in a quandary when faced with the question of passing, or otherwise, civilian instructors who had gone to it for training in Central Flying School methods.

However, it was the common or garden average civilian pupil that he wished to consider, for it was from this class that the greatest support was forthcoming in the various schools and clubs engaged throughout the country. His pocket was usually the limiting factor and, unfortunately, the author had advanced no solution of this or of the two or three other handicaps to which civil schools were subject. If it were made too difficult for the pupil, he would be choked off before he started; if it were too easy, he would probably kill himself, and someone else. Possibly some amelioration of the difficulty might be attained by abolishing the idea that no two pupils under instruction should go up together, with two control sticks. Surely, if it were the responsibility of the instructor to see that only two sensible people went up together, and if it were understood that one was captain of the ship, then he believed the halving of the cost between them would go far not only to encourage more flying, but also to add that most essential and hardly-won feature—experience. In this connection it might be of considerable advantage to arrange that one of the control columns would be put out of action immediately in case of emergency. A gear for such a purpose had been fitted in one or two foreign machines, and it was difficult to understand why the idea was not more popular here.

Finally, he could not help thinking that this very high-brow form of instruction, valuable as it was for training instructors, was hardly adaptable to the varied mentalities of the average pupils. In commercial practice one was bound to study a compromise between ultra efficiency and mere safety. Check up the pupil at regular intervals, by all means, give him categories too, if such practices could be honestly observed; but make it easy for him to gain experience. That was the greatest of all teachers, and properly conducted schools should not find it expensive to give.

Captain G. F. Guest (Deputy Master, Guild of Air Pilots and Air Navigators): He was particularly impressed by the extraordinary similarity of interest between the Guild of Air Pilots and the Royal Aeronautical Society. The two seemed to be drawn together automatically by this extremely important subject, and he hoped that it meant a strengthening of the link between the two organisations. They must appreciate the directions in which the various aeronautical bodies were inter-dependent, and where they relied upon each other for technical knowledge and assistance.

Mr. Lawrence A. Wingfield (Clerk, Guild of Air Pilots and Air Navigators): He associated himself whole-heartedly with the remarks of Captain Guest as to

the success of the first paper read before a joint meeting of the Royal Aeronautical Society and the Guild. The training of pilots and instructors was of the very greatest importance and interest to the Guild, particularly at this time, for it was only during the last few months that the Guild had sought to find some solution of the problem of civil flying instruction. A point which emerged clearly from the discussion was the fact that, while the civilian schools would continue to look up to and make use of the Central Flying School as a model which, by reason of its very long experience and the very high degree of care and judicial consideration which had been given to the subject, was an excellent model in every way for the civilians to follow, yet for the time being, at any rate, it would not be possible to apply the " sequence of instruction " for civil schools to the same degree, and the latter would depend upon rather more rule-of-thumb methods. For example, the author of the paper had said that aerobatics were essential to an instructor, and that he should encourage his pupils in that direction. Quite a few of the civilian flying schools, however, used aircraft which were definitely not licensed for aerobatics. The Guild would, however, through its Panel of Examiners, evolve a standard of instruction for civil aviation. In time that standard would be gradually improved, and the Guild would always have before it the model of the Central Flying School. He felt certain also that the Guild would have the benefit of the counsel and assistance of the Central Flying School whenever it was needed.

Finally, Mr. Wingfield welcomed this opportunity of cementing not only the liaison between the Royal Aeronautical Society and the Guild, but also the liaison, which hitherto had existed largely by correspondence, between the Central Flying School and the Guild.

Reply to Discussion

From the Royal Air Force point of view the use of gliders for flying instruction had not been tried out to date. Whilst agreeing that training by means of gliders might certainly help to " lighten the hands " of a pupil, he rather viewed with alarm the position of a chief instructor when six *ab initio* pilots were all trying to make the ground.

He thanked Mr. Griffith Brewer for having corrected him with regard to dual control, but added that it was not the intention in the paper to make a complete list of the machines fitted with dual control.

Commenting upon Flight Lieutenant Jenkins' criticisms concerning instrument flying, and as to whether or not sensory flying should be discarded, he said that perhaps the statements made in the paper in that connection were rather misleading. He had still an open mind, and agreed that probably the ideal was a combination of both, but he had put it forward as a suggestion that perhaps it would be possible to train a pilot to fly by instruments entirely, whereas it would not have been possible to train that same pilot to fly by sensory methods. He had put it forward deliberately with a view to provoking discussion, because there were at least one or two people who had been concerned with flying instruction over a period of several years and who believed firmly that instrument flying would be the mode of flying in the future.

With regard to the remarks of Mr. Scott Hall as to the ideal training aircraft, he said quite frankly that the characteristics he had mentioned were supposed to represent the ideal to be aimed at. Perhaps he had asked too much, as had been suggested; but he had had in mind, when he had stated the ideal requirements, the fact that when the " Avro " was first introduced it was turned down as being much too difficult an aircraft to use for training, but it had, nevertheless, reproduced the conditions that were needed. The radial engine on that machine gave pilots quite a good experience as to how to deal with torque when they piloted the Service type of machine; the narrow undercarriage was useful for

teaching cross-wind landings, and so training them to land in small fields, which had to be done in France. When he had stated that the training aircraft should reproduce the characteristics of the modern high-powered type, perhaps he had been rather carried away by the fact that the " Avro " did enable us to turn out the type of men that were wanted in France. However, he still maintained that it should be possible to get a light aircraft which provided very much the same handling effect as in the present-day larger aircraft. He had in mind certain types which were used when the Royal Air Force was experimenting with machines suitable for elementary flying. They were not, strictly speaking, light aircraft, but they were capable of easy handling on the ground, and certain of them did definitely reproduce the characteristics of modern Service aircraft—a factor which he considered essential. When stating that the aircraft should have no vices, he had meant that it should have no *training* vices. By that he meant he considered as vices not only such behaviour as a tendency to suddenly flick into a spin when stalled, but he would put down as a training vice any tendency to hunt on the rudder, etc. That would affect the feelings of *ab initio* pilots who had not received instruction on the type beforehand. They would imagine that the instructor still had his feet on the rudder bar and was maintaining a certain measure of control.

It was difficult to be more definite than he had been concerning the performance of training aircraft. To have a landing speed exceeding 40 m.p.h. would make elementary training rather difficult, and he considered a top speed of 110 m.p.h. was sufficient to give a pupil an idea of speed. Then he had specified adequate climb to prevent loss of time between lessons or manœuvres. If aircraft constructors could produce machines embodying something like the characteristics he had stated, we could leave them to decide the actual speeds.

He agreed with Flight Lieutenant Johnson that air brakes assisted training tremendously by varying the performance of the aircraft. But they might also add to the difficulties of the instructor, for he had seen a considerable number of people rumbling in on the air brakes. One could show a pupil how to use them, and he would use them quite a lot and, indeed, would rely on them, just as he did on the engine.

The questions with regard to instruments he would prefer to leave to Flight Lieutenant Johnson, from whom he had learned all that he knew about them.

The remarks with regard to the " S " turning was not an Air Ministry order, but was a suggestion which had been circularised in his own area.

Perhaps Captain Travers was a little hard on the Service when he had referred to their ability to break up their aircraft without having to pay for them. However, he (Group Captain Baldwin) did welcome the liaison between the Service and civil aviation and that liaison would continue, because those in the Service realised that they could learn from the civil side. He hoped it would prove of value to both. The idea had originated from the Central Flying School that certain Air Force Reserve officers should take an abbreviated instructors' course or a refresher course at the school. He gathered that there had been certain difficulties which had prevented this suggestion being adopted. Another suggestion was put forward, that the Air Ministry might come to some agreement with Reserve officers who were already qualified Central Flying School instructors but had gone out into civil life that, instead of putting in twenty hours at the civil school, they might put in a certain number of hours as instructors at the flying clubs. That would be a most excellent idea, and in the event of another war, when it would become necessary to call for extra instructors, these men would be available as an immediate reserve. There was yet another suggestion, that all flying officers on the Reserve should go through an abridged course of C.F.S. instruction during their annual training, and the R.A.F. authorities responsible for keeping track of the Reserve officers should have a return rendered by Han-

worth, or whichever school was concerned, which return would classify them either as being useless as instructors or as likely to be good " B " type instructors, and so on. By such means the liaison between the Service pilots and civil aviation could be tightened up. He felt certain that he was speaking for all Air Force officers concerned with flying training when he said they would help, and indeed had helped, all they could to foster that liaison. He was most happy to know that a panel of flying instructors was being formed, because as a private owner, and one who had called at certain flying clubs, he must admit that during his three years at the Central Flying School he had begun to view with alarm the methods of certain so-called instructors in various parts of the country.

Finally, Group Captain Baldwin expressed his thanks to Flight Lieutenant Johnson for the assistance he had given him in connection with instrument flying, and to the three officers who were his chief instructors while he was at the flying school, and from whom he had learned much and who had given him the greatest assistance in preparing these notes.

Referring to Captain Preston's remarks.—He refers to their high-brow forms of instruction and the difference between the training of instructors and pilots. This difference was realised, but in the time available it was considered best to concentrate on the system whereby an instructor was trained as this automatically covered the training of a pilot which is a far simpler matter.

SOME NOTES ON THE DESIGN OF AEROPLANE CONTROL SURFACES AND CONTROL SYSTEMS

BY

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PILCHER MEMORIAL PRIZE PAPER, 1931-32

Paper read before the Students' Section of the Royal Aeronautical Society, in the Library of the Society, on March 17th, 1932, at 6.30 p.m., H. E. Wimperis, Esq., C.B.E., M.A., F.R.Ae.S., Director of Scientific Research, Air Ministry, in the Chair.

Introduction

The control of an aeroplane is effected through the medium of three distinct sets of control surfaces known as the elevators, ailerons, and rudder, these surfaces being so disposed with reference to the centre of gravity of the machine as to be capable of producing rotation about three mutually perpendicular axes passing through this point, and called the lateral, longitudinal, and normal axes respectively. Thus, the elevators cause a rotation about the lateral axis of the machine, the resulting motion being known as pitching, the ailerons a rotation about the longitudinal axis, producing rolling, and the rudder rotation about the normal axis, producing yawing.

An aeroplane is controlled from the pilot's cockpit, usually by means of a control column and a rudder bar, the former for operating the elevators by fore and aft movements and the ailerons by lateral movements, and the latter for operating the rudder. The ailerons are interconnected to work together, but in opposite directions. The system as a whole is so arranged that a backward movement of the control column elevates the nose of the machine, a movement to starboard gives starboard bank, and starboard rudder gives a starboard turn, and conversely.

The controllability of any aeroplane as provided by its control system will vary with the requirements of the design, but in all cases the inter-relationships which exist between this factor and those of stability and manœuvrability must be fully understood before the system can be efficiently designed. Thus, a machine of the fighter class, where extreme manœuvrability is an essential to the design, has but small inherent stability and a very powerful control system. On the other hand, in the flying qualities of a heavy passenger machine extreme manœuvrability is uncalled for, and what is sought after is a well balanced machine both easy and light to fly, with a control system sufficiently powerful to offset, when required, the high degree of inherent stability usually present in this type of aircraft.

Additional control surfaces in the form of an adjustable tailplane, variable camber gear for the wings, and wing tip slots, are often incorporated in modern control systems, but their inclusion in the present paper is limited to a brief reference only, the design of the essential control system comprising the elevators, ailerons, and rudder, forming the basis of the following discussion.

It is proposed to consider the factors influencing the aerodynamic design of the control surfaces, and those influencing the structural design of the complete system, under two distinct heads to facilitate the interpretation of the conclusions reached.

Aerodynamic Design of the Control Surfaces—Ailerons

In contemplating the design of the ailerons, the two following desirable features should receive special attention with a view to their attainment.

(*a*) That the ailerons shall be well balanced and light in operation.

(*b*) That the lateral control shall retain its effectiveness during slow speed flight at high angles of incidence.

The first requirement is to ensure that the aileron control shall harmonise with that for the other sets of control surfaces (since, without care, it is likely to come out the heaviest of the three), and may be said to have been met, when, for a given ratio of gearing between control column and aileron, the lateral force to be applied to the former does not exceed some 10 or 12lbs.

The second requirement of providing adequate lateral control at the stall, is complicated by the fact that normal type ailerons when operated so as to produce a rolling moment about the longitudinal axis of the machine, do so at the expense of setting up large yawing moments due to differences of aileron drag at opposite wing tips, the ratio of rolling moment to yawing moment substantially falling off with increase of wing incidence, and causing the lateral control to become increasingly ineffective.

With a view to the reduction of stick forces, in those cases where the lateral control system is likely to appear heavy in operation, aerodynamic balancing of the ailerons is frequently resorted to. Balancing action may be secured by suitably disposing a portion of the movable surface ahead of the aileron spar, thus bringing the c.p. nearer to the hinge axis, and reducing the net moment of load, due to the complete system, about that axis, or by means of servo control. The working of the balance should be independent of aileron setting and angle of incidence, and the value of the hinge moment should remain substantially unchanged. Moreover, over-balancing is to be avoided, since sudden changes in the attitude of the machine will encourage the surface to take charge and " throw-back," and, to offset this possibility, it is desirable that, at all times, the control column should offer a small resistance to displacements from neutral.

The " horn " type of balanced aileron is often favoured in design, and serves to bring about a marked reduction in hinge moments at small angles of incidence, but the inconsistency of effect due to changes in this variable is its principal drawback to general application, requiring progressively heavier stick forces as the angle of incidence is increased, and would appear to be best suited to machines of the fighter class, where full throw of the ailerons may be expected to occur while flying at the maximum speed of horizontal flight. Since the horn is out in the free air while the remainder of the aileron is working behind the fixed portion of the wing ahead of it, the airflow over these two component parts of the same surface assumes a different form, resulting in a difference in the rates of change of the individual centres of pressure for a given change of angle of incidence. The c.p. of the balance is normally ahead of the hinge axis, and, by setting up a moment in opposition to that due to the pressure of the air forces on the surface, helps to turn the aileron in the direction required. As the angle of incidence is increased, however, the c.p. moves back towards the hinge, thereby causing a drop in the value of the balancing moment that can be provided and calling for heavier forces at the stick. The shaping of the horn to an aerofoil section, in preference to one that is symmetrical, is likely to secure a smoother working of the surface. Structurally, the horn type balance has the advantage that the amount of balance area may be easily altered to meet require-

ments as dictated by full-scale flight tests of the " feel " of the lateral control; but it has the disadvantage of being susceptible to torsional vibration.

An alternative to the horn type of balance, referred to above, is provided by the use of an auxiliary surface of high speed ratio, mounted above the aileron on brackets attached to the control surface spar, and so arranged that its c.p. is always ahead of the hinge axis. Although adding something to parasite resistance and detracting from a neat appearance of the machine, variations of hinge moments with changing incidence are relatively slight and alterations in balance area are simply carried out, thus making this form of balance particularly suited to heavy machines of large span where lightness of control may take priority over the attainment of a high performance.

The advantages accruing to the use of balanced ailerons are likely to be greatest for designs in which balancing is secured by means of the backset hinge method. The constancy of the hinge moments obtainable, together with its almost complete indifference to changes of angle of incidence, make this form of balance eminently suitable for all classes of machines in which the structural difficulties in connection with the support of the surface from the wing structure can be overcome. The value of the hinge moment is primarily controlled by the distance of the hinge axis behind the leading edge of the surface, which latter appears to be best located at from 30 to 35 per cent. of the aileron chord, according to the absolute size of the machine and the aerofoil section of the wing. At extreme angles of throw, and for a given attitude of the machine, the rolling moment that can be provided by backset hinge balanced ailerons, as compared with that obtainable from normal type ailerons having the same total area, will, in general, assume a somewhat smaller value, owing to the more turbulent airflow over the surface of the former created by the opening up of an air gap between the leading edge of the balance and the rear portion of the wing ahead of it, and, if necessary, the area of the balanced aileron and/or its range of angular travel should be increased to ensure that a reduction of stick forces is not obtained at the expense of a sacrifice in effectiveness of the lateral control. Rounding of the balance to a symmetrical section in preference to leaving it with a blunt nosed leading edge, is conducive to a smoother airflow from wing to aileron, and is to be recommended. Structurally, the support of backset hinge ailerons from the wing structure presents some difficulty due to the location of the hinges, the rigidity imparted to the outriggers being a function of the wing depth and its torsional stiffness, and being greatest when the latter are high. Moreover, an alteration in the amount of balance is not easily effected following the assembly of the surface to the machine.

Having discussed suitable means of reducing stick forces and ensuring that the ailerons will be light in operation under all conditions of flight, we may now turn our attention to the elimination of yawing moments due to aileron drag with a view to establishing an effective lateral control at the stall.

The origin of the yawing moments, referred to above, and the detrimental effects which they have on control may conveniently be investigated by considering the aerodynamic behaviour of the ailerons when the control column is set, say for starboard bank. In this position, starboard and port ailerons will be respectively raised and lowered, above and below, their neutral settings, and by equal amounts. The effective camber of the portside wing will be increased, thereby, in excess of that obtaining on the starboard side, resulting in a difference of lift at the two wing tips, and producing a rolling moment about the longitudinal axis of the machine in the direction of bank desired. At the same time, however, the dissymmetry of the two ailerons with respect to the aerodynamic section of the wing, leads to the drag of the downturned flap being in excess of that for the upturned one, due to the more streamlined attitude of the latter, giving rise to a yawing moment to port and causing the machine to turn about the raised wing tip. This has the effect of increasing the airspeed

over the opposite wing tip, which thereby suffers an increased lift, setting up a rolling moment due to yaw in opposition to the rolling moment due to lift and tending to put on opposite bank. Moreover, as the angle of wing incidence is increased, and for a given control setting, the effectiveness of the aileron in producing rolling due to lift, falls off, while the yawing action becomes more pronounced. Control at the stall thus becomes precarious, inasmuch that should the machine drop a wing tip and the ailerons be operated to restore it to an even keel by pulling down the flap on the side that is low, the rolling moment due to lift is insignificant in comparison with that due to yaw, for this attitude, and the trouble is aggravated still further. The yawing tendency may be corrected by the use of the rudder; but, since it is clearly desirable that the functioning of the individual control surfaces should be independent of each other, recourse should be made to a revision of the aileron design, either in the alteration of the disposition of its area or its aerodynamic cross-section, or in the control system employed for its operation.

Aileron areas usually lie between seven and nine per cent. of that of the wings; their span varies from one-third to two-thirds the semi-span of the wings, but in special instances where the aileron span is designed to operate as a torque tube by the inner end being connected direct to the pilot's control system, or where it is used in conjunction with, or in lieu of, a flap gear, they may extend the full length of the trailing edge. High aspect ratio of the ailerons increases the slope of the curve of lift coefficient against angle of incidence (and hence the lift per unit area) and is favourable to an increase of rolling moment; where the chord width is constant, it should lie between 25 and 28 per cent. of that of the wing, its absolute value for a given controlling effect taking into account the aerodynamic characteristics of the wing section and the maximum throw that can be provided by the control system. Moreover, it is probable that aileron effectiveness will be influenced by the ability, or otherwise, of the wing structure to resist torsional deflection under load. With the object of reducing the end losses from the wing the ailerons are sometimes inset from the tips, an arrangement which increases the lift per unit area and slightly improves their efficiency. Lateral control as affected by the shape of the wing tip is benefited when the latter possesses a negative rake (up to some 30°) and rounded edges, a form which makes for lightness of control generally, and serves to reduce the load to be applied at the stick.

In seeking to counteract yawing tendencies by a change of cross-section, the Frise-type aileron may be mentioned. This design is a modification of the backset hinge balanced aileron, in which the balance portion is so shaped that the downturned aileron remains screened behind the wing, while the opposite one projects its leading edge below the aerofoil, thereby increasing the drag on that side, and thus attempting to reduce yawing action by an equalisation of drag forces at opposite wing tips.

Low speed control as affected by the control system is considerably improved when the ailerons are designed to be differentially operated. As distinct to the working of normal type ailerons whereby a given movement of the stick causes equal and opposite displacements away from neutral, the differential control provides that the rate of movement of the upturned surface is always in excess of that for the downward one, thereby attempting to eliminate yawing moments through an equality of wing tip drag forces. Mechanically, the differential action is often brought about by an application of the dead-centre principle of gearing, and, when this is so, large lateral movements of the control column cause the downturned flap to reach its dead-centre position first, and the surface thereafter commences to return towards its original setting, both ailerons now rotating in the same direction with the displacement of the upturned one still increasing. The superiority of differential ailerons over those of normal

design, at high angles of incidence, amounts to little for small displacements from neutral, but with increasing aileron angle it becomes the more clearly marked, and assumes its greatest importance at a setting approaching their full throw. In this attitude the rolling moment due to lift is a maximum and is little inferior to the value obtainable from standard ailerons of the same total area, while the yawing moment due to drag is very nearly zero, the ratio of rolling moment to yawing moment for the differential system being some three times in excess of its value for the other. Differential ailerons thus provide for increased safety and control at the stall, and are, therefore, often favoured in the design of the lateral control system.

Of the several successful schemes that have been evolved for the amelioration of lateral control in slow speed flight, and that have been applied in practice, the interconnected slot and aileron control is outstanding among them in its suppression of yawing moments and maintenance of aileron effectiveness with changing incidence, and appears to offer the nearest solution to this vital problem. The working of the control is such that downward movements of either aileron cause a slot to be opened at the leading edge of the wing, the width of which increases progressively with increasing aileron angle, but that for upward aileron movements the slot remains always in its closed position. It is a property of any wing section that changing incidence modifies the type and nature of the airflow over its surface, a steady and regular flow existing up to the angle of maximum lift, which breaks down, becoming turbulent and disturbed, when this point has been exceeded. The breakdown of the airflow is attended with a marked decrease in lift and a large increase in drag, and affords an explanation of the inefficient working of the lateral control of the normal type of unslotted wing at high angles of incidence, where full throw of the ailerons often proves inadequate in raising a wing tip that is low. The opening of a slot at the leading edge of the wing just prior to the critical angle being reached, as incorporated in the interconnected slot and aileron control, prevents loss of control due to burbling, by the maintenance of a steady streamline flow from wing to aileron. The arrangement is such that when the incidence of the wing as a whole is large, that of the slot is relatively fine. The auxiliary surface thus works efficiently in producing lift and causes the air to flow smoothly over its surface on to the wing behind it, thereby augmenting the lift and considerably reducing the profile drag of the part concerned. The object of the slot being to counteract yawing tendencies due to aileron action, it is arranged to operate in conjunction with the downward moving aileron only, thereby attempting to secure a balance of wing tip resistances by a reduction of wing profile drag on the side where aileron drag is the most pronounced. The value of the slot as an aileron adjunct is noteworthy in the independence of aileron action with changing incidence, and the constancy of effect which it imparts to the lateral control. Rolling moments due to lift actually increase with increasing angle, while the value of the yawing moment is at all times small. At angles well in excess of that of maximum lift, the yawing moment frequently changes sign; the rolling moment due to yawing acting in the same direction as the moment due to lift, and assisting in applying bank to the machine, instead of offsetting it, as is usually the case. The slot and aileron control in addition to showing an independence of working with changing wing incidence, is but little influenced by the setting of the control flap, aileron drag being at all times small and maintaining an appreciably constant value.

Occasionally the inner portions of a wing are provided with movable trailing edge flaps which may be used together with or independently of the ailerons to effect a variation in camber of its aerofoil section to meet a specific requirement. By displacing the flap well below its neutral setting, the flap gear causes the airflow over the wing to bank up against its lower surface with increased pressure, thus augmenting the value of the lift coefficient and allowing

of a reduction of the minimum speed of horizontal flight. The downturned flap, moreover, gives rise to a marked increase of wing resistance, which latter may be profitably utilised to steepen the flight path of a machine gliding down to land, and, when the wheels have touched the ground, cut down the subsequent landing run by acting as an effective air brake.

Elevators

Although, strictly speaking, the elevator only constitutes the movable trailing edge flap of the horizontal tail surfaces, in many machines the tail setting may be varied during flight. The latter arrangement allows of the true elevator being held locked in its neutral position, while longitudinal control is maintained by a change in incidence of the tail considered as a whole. The design of the elevator may thus be conveniently discussed together with, and in relation to the tailplane ahead of it.

The combined area of tailplane and elevator usually lies between 9 and 16 per cent. of that of the wings, the movable surface constituting from 30 to 50 per cent. of the whole. The absolute value of tail size and the ratio of fixed to movable surface is decided by considerations of the aerofoil section and aerodynamic properties of the wing, of the weight of the machine, and the distance of the tail behind the centre of gravity. Other things being equal, a thin aerofoil section, or one with a convex lower surface used in conjunction with a wing of high equivalent aspect ratio, serves to cut down c.p. travel along the chord and requires a smaller tail surface to give balance than a wing in which the aspect ratio is low and the wing section deep, or formed with an abrupt concavity of the lower surface near the leading edge. A reduction in tail size can also be effected where manœuvrability is unimportant, as in heavy passenger machines and machines of the night bomber class, where structural requirements lead to the use of a biplane form of tail, the tail area must be sufficiently increased above the minimum prescribed by the use of a single surface to compensate for the loss of efficiency of the former due to interplane interference. Tail area as affected by the fore and aft location of the c.p. behind the c.g. of the machine may be somewhat reduced as the distance between these two points is increased, to produce the same controlling effect; but, since a backward shift of the horizontal surfaces leads to an increased longitudinal moment of inertia of these parts, the tail area will vary at a slower rate than dictated by the reciprocal of the moment arm about the c.g. of the machine.

The presence of the fixed portion of the tailplane working ahead of the elevator makes for lightness of control in setting up a given pitching moment about the c.g. of the machine. Thus, a displacement of the flap from its neutral position, by offering a deliberate obstruction to the airflow over the tail, reduces the velocity of the latter in passing over the stabiliser, which, in its attempt to escape, banks up against that surface so as to augment the air pressure acting thereon. A proportion of the resulting pitching moment is thus provided directly by the tailplane without assistance from the pilot, only the moment of load about the elevator hinge having to be balanced at the control column. The effectiveness of the tailplane in reducing elevator control loads is likely to be greatest for tail surfaces possessing a negative rake at the tips and so arranged that the span of the stabiliser adjacent to the control flap spar is in excess of the maximum span of the elevator behind it. The lift per unit area (and hence the pitching moment obtainable from a given setting) of the elevator increases with increasing aspect ratio of that surface, so that the elevator chord is often located between one-third and one-quarter of the full chord of the tail section. A high aspect ratio of the flap is most easily met by machines in which the tail surface is supported on outriggers extending from the wing structure; a form of design which eliminates fuselage interference, and reduces the end losses from the lateral component of spin of the airscrew slipstream.

The aerofoil section of the tail is usually of symmetrical form or such that the maximum convexity below the chord is about one-third of that above. A thick section is favourable to structural efficiency and is often chosen in design. The aerodynamic characteristics of the section should include that the airflow over its surface remains stable at high angles of wing incidence so that a loss of longitudinal control will not be experienced at the stall.

Where the elevator surface is comparatively great, as in machines of large gross weight, or where its aspect ratio assumes a low value to meet structural requirements, control loads are likely to become excessive, and aerodynamic balancing of the control flap is often resorted to with a view to securing a reduction of stick forces. The balance may assume a variety of forms, the commonest applications in practice being the " horn " and " backset-hinge " types respectively, of which the latter claims first place in respect of balance effectiveness and constancy of action with changing wing incidence; the horn type of balance is, however, often used, on account of its simplicity of construction and the ease with which an adjustment of balance area can be effected. In all cases the working of the balance is such that by suitably disposing a portion of the movable surface ahead of the hinge axis, the c.p. of the flap is brought nearer to that point and the resulting moment of load about the hinge axis (and therefore the force required to give balance at the stick), correspondingly reduced. Increasing the aspect ratio of the elevator, by reducing the chord length for a given span, serves to bring the c.p. of that surface nearer to the hinge axis for a given flap setting, and is often sufficient in itself to counteract heaviness of control.

Rudders

The combined area of the vertical tail surfaces usually lies between 3·5 and 5·5 per cent. of that of the wings, the movable surface constituting from 40 to 100 per cent. of the whole. The fixed fin ahead of the control flap may be completely suppressed in the case of multi-engined machines fitted with two or more rudders located between the planes of a biplane form of tail, where bracing difficulties are likely to be met with, but, since—aerodynamically—the fin surface tends to lighten control forces at the rudder bar by allowing the air pressure acting on the rudder, when displaced, to bank up against it, thereby securing part control from a fixed surface independent of the pilot's control system, the fin will, ordinarily, be always fitted. The aspect ratio of the rudder should be high to secure a maximum control from a given area and to bring its c.p. nearer to the hinge axis. The use of a high aspect ratio, however, is often limited by considerations of stress in the fin post to which the control flap is braced, so that heaviness of control is often corrected by the use of aerodynamic balance, the horn-type balance being widely used in design. For single or tandem-engined machines where the line of thrust is contained within the plane of symmetry, the area of the rudder may be somewhat reduced with increasing distance of its c.p. behind the centre of gravity, and when manœuvrability is unimportant, or where the centre of side resistance of fuselage and tail, for a small angle of yaw, acts well aft of the c.g. of the machine. A cut in rudder area should, however, be made with discretion, due regard being given to likely changes of fuselage interference with changing wing incidence, and it is preferable that the absolute value be made somewhat higher than the bare minimum dictated by theoretical analysis, that a positiveness of control may obtain at the stall, so that the prevention of, or recovery from, a spin may be under the full control of the pilot.

A special problem in connection with directional control power arises in the case of a machine fitted with wing engines, wherein the sudden stoppage of a motor will leave an eccentric thrust about the c.g. that must be corrected by use of the rudder. When designing the rudder, therefore, the complete failure of either unit should be contemplated, and the control made sufficiently powerful

to effect a turn about the working engine when the latter is running at full throttle and the machine flying at its maximum all-up weight. Thus, a sudden cutting out of the starboard wing engine, say, will call for an application of left rudder for the maintenance of a straight flight path, and the remaining travel of the flap between such setting as may then be called for and the full throw of the controls, should be adequate to yaw the machine to port with the portside engine developing its maximum thrust horse-power. The above requirement is most easily met by providing the machine with twin rudders, operating as normal control flaps, together with a central fin that may be suitably offset from the centre line of the machine, to meet the case of engine failure.

The design of the rudder flap is often complicated by its being so located with respect to the thrust axis of the airscrew that a considerable portion of its surface is subjected to airscrew slipstream interference, a factor which should always be allowed for in any calculation of control effectiveness.

Thus, unless the rudder area be symmetrically disposed with respect to the prolongation of the thrust axis of the airscrew (allowing for change in inclination due to downwash from the wings), the lateral component of spin of the airscrew slipstream, acting against that surface, will cause the machine to yaw about its c.g. in a direction depending on the ratio of areas above and below the datum axis, and the direction of rotation of the airscrew. Except in the case of certain seaplanes and machines in which the vertical tail surfaces are carried by tail booms from the wing structure, the use of a symmetrically-disposed rudder is prohibited by landing considerations, so that, in general, the airscrew axis will be located well below the mid-point of the rudder depth. Considering the case of a machine fitted with a right-hand tractor airscrew and a rudder of constant chord, the lateral pressure acting upon the surface above the axis, in a direction from port to starboard, will be in excess of that acting below in the opposite sense, thereby tending to yaw the machine to port and requiring the application of right rudder to maintain a straight course. Yawing action, due to slipstream effects, is particularly severe for machines in which the fuselage is comparatively short and of good streamline form, and the engine power high, *e.g.*, machines of the single-seat fighter class. In cases such as this, a sudden opening of the throttle will demand sufficient application of right rudder to displace the control flap well beyond its neutral position if a straight flight path is to be held; so that, if the rudder is to be relied upon for manœuvring on the ground while taxying, it may prove incapable of providing an adequate maximum of control for turns to starboard. If the rudder is to operate within the slipstream, therefore, with a maximum of effectiveness, it is advisable that the arrangement of its area be such as to locate the maximum chord at or below the point of intersection of the airscrew axis, so that, by equalising the areas affected above and below that axis, the unbalanced side force may be correspondingly reduced. Moreover, to reduce the load on the rudder bar at the pilot's foot, it is advantageous to provide the control flap with a suitable balance working in the free undisturbed airstream outside of the airscrew disc, that its c.p. may be brought nearer to the hinge axis and the moment of load about that point reduced. Yawing tendencies, due to slipstream action, may also be corrected by offsetting the fixed vertical fin, working ahead of the rudder, some two or three degrees from the longitudinal centre line of the machine, or by giving the vertical surfaces an aerofoil section unsymmetrical about its chord. A rudder bias gear is often fitted to the rudder bar to relieve the pilot of undue fatigue in holding the control flap in a displaced position for considerable periods while flying straight.

Structural Design of the Complete Control System—Control Surfaces

Essentially the control surface structure will consist of a main spar placed at or behind the leading edge, according to the position of the supporting hinges,

and designed to carry the total load occurring on the surface, to which is attached the ribs, forming the aerodynamic section of the surface, and leading and trailing edges to give the required plan form. The covering of the surface will be either of fabric, or of a rigid nature employing plywood or a light gauge metal, the latter stiffening up the structure generally and reducing deflection under load.

When a fabric covering is used, the inner and outer edges of the surface will be suitably stiffened to resist the compressive loads arising from the fabric tension due to doping, and to guard against accidental damage occurring during rigging. Control is usually effected by torsion of the main spar through the medium of an operating lever conveniently attached thereto and connected up to the control circuit from the cockpit. Sometimes this lever is wired back near the trailing edge to a special compression rib, when lateral stringers will be provided to ensure a fair proportion of the total load on the surface being taken off at the wire and transferred direct to the lever, thus reducing the torsion on the spar and limiting trailing edge deflection.

Dealing first with the design of the control surface spar, the form of its cross-section and the choice of material specification will be decided by limitations of shear and direct stresses in the material under an instantaneous combination of loads due to torsion, lateral shear and lateral bending, arising from the fore and aft position of the c.p. along the chord and to the load distribution along the span respectively; also, its absolute depth will be the depth of the aerofoil section of the control surface at that point on its chord where the spar is to be located.

When constructed in wood, the spar is usually of box section, with spruce flanges and spruce or ply webs, whilst in metal construction a tubular member in H.T.S. or duralumin is often favoured. Now, it is well known that the distribution of area in a tubular section is an uneconomical one to resist direct stresses due to an applied bending moment acting alone, and that its principal recommendation lies in its high resistance to deformation under torsional loads. The applied torsion will, in general, be highest in the case of unbalanced control surfaces of low aspect ratio wherein the employment of well-known beam sections such as the I,], etc., might cause failure of the spar through torsional instability; but the torsional resistance of these sections will be considerably increased when used in conjunction with a rigid control surface covering of plywood or metal, in which form they are sometimes to be found. For production purposes the tubular section has the advantage that, within limits, it is readily obtainable from stock. In very large machines, however, employing thick section wings, it may prove more economical to employ a built-up tubular section in H.T.S. strip in a lighter gauge than could be obtained in the form of a solid drawn tube of the same diameter. Bending stresses in the spar may be considerably reduced by a judicious choice of the number and position of the supporting hinges and the control surface lever. The outermost hinge position will also be governed by considerations of overhang deflection and vibration, especially in the case of control surfaces employing the horn type of balance. The lateral shear on the spar is easily provided for and rarely influences the design of this member. Holes in the spar must be carefully avoided since their existence would cause high local stresses to be set up in the material adjacent to their edges, thus encouraging instability of the spar walls; but, in so far as hinge design or other attachment fittings cause them to be present, the spar section should be adequately reinforced at these points with a diaphragm, sleeve, or liner, to meet the conditions obtaining.

Ribs will be designed as beams cantilevered from the spar, carrying a total load proportional to their pitch, and with a distribution over the chord decided by the attitude of the machine. In large machines, these members may assume the form of a braced girder, in which case the total shear on the rib should be transferred to the spar via the shear bracing, and the overhang bending moment

by end loads in the flanges. The girder-type rib may be of wood or metal construction, the former invariably employing spruce throughout for both flanges and braces, whilst duralumin is often favoured for the latter, a tubular channel, tee, or angle section being employed for either or both flanges and braces, these being united by duralumin clips or gusset plates, and solid or tubular rivets. With either design special care is taken to ensure an efficient spar connection. An alternative construction to the above is a welded tubular frame in a low carbon or chrome-molybdenum steel, which, by the elimination of mechanical joints, tends to simplify the structure. Yet another design is a wooden rib built up of spruce flanges and plywood webs, with lightening holes at suitable intervals, and stiffened where necessary with vertical side pieces; the metallised version of this form of construction is a one-piece pressing in sheet duralumin, the flanges being bent at right-angles to the web, and the lightening holes flanged to impart stiffness to the flat plate. In the case of fabric-covered surfaces, the ribs must be able to withstand the compressive loads induced in them by the tension in the fabric due to doping, which averages some 3 to 4 lb./in. run; also, where the surface is designed to be wired-back, the end load component of the load in the wire must be resisted by the compression rib to which it is attached.

Operating levers for control surfaces are either of the flat plate type or of built-up construction, in which two similar mild steel sheet pressings are welded together at leading and trailing edges to form an oval or streamline cross-section. The plate type lever is usually made in heavy-gauge duralumin, such as 6 s.w.g., and is best suited to small machines with lightly-loaded surfaces; but where bending stresses are likely to be high and the lever is to be exposed to the air-stream, it is more economical to employ the built-up form. The lever will be mounted on the spar with its centre line normal to the direction of pull or thrust coming upon it from the operating cable or push-pull rod when the control surface is in its neutral position. It would appear advantageous to place the lever and its operating system below the spar rather than above it, where this can be satisfactorily arranged, since, in this position, the airflow over the upper surface of the aerofoil section (which largely influences its aerodynamic properties) will be unaffected thereby. Alternatively, the lever may be designed to operate within a suitable fairing. The lever attachment fitting must provide for sufficient bolts or rivets being used to ensure that shear and bearing stresses in the parts united are kept within safe limits.

The supporting hinges for the control surface are usually of the plain journal or ball-bearing variety, and must be designed to provide an adequate bearing surface and work without undue friction; to facilitate alignment during rigging, the number used will be the minimum consistent with the limitations of spar stresses and deflection under load. Hinge housings may be located within the spar itself in a suitable fitting attached thereto, or, in the case of surfaces employing the back-set hinge type of balance, in an extension of the compression ribs behind the rear spar. Where a lubricant is used for the hinge bearing this must not penalise the smooth working of the surface at high altitudes, or in cold climes, due to too high a coefficient of viscosity obtaining under these conditions. To guard against this and the possibility of jamming due to ice formation, the hinges should be shielded from the air-stream or suitably lagged. A special point in connection with the design of the control system is to guard against the possibility of control surface flutter or vibration occurring during high-speed dives or when the controls are operated so as to cause a sudden change of attitude of the machine. The occurrence of this phenomenon encourages structural failure of the parts concerned and endangers the safety of the machine, so that its non-existence is a feature of good design. The causes of control surface flutter are many and various, and are related to the flexural and torsional stiffnesses of the main supporting surfaces to which they are attached; but the following design recommendations for its prevention may be noted:—

(*a*) Irreversibility of control of the surface;
(*b*) Surface balanced statically;
(*c*) Surface underbalanced aerodynamically;
(*d*) Moment of inertia of surface small, for the ailerons, in addition to the above;
(*e*) At least one-half of the aileron span should lie inboard of the outermost external wing bracing;
(*f*) Where the ailerons are supported from a false spar, this should extend across the whole wing.

From an aerodynamic standpoint the wing section should have a small c.p. travel, and the airflow over its surface should remain steady for a sudden change of angle of incidence. Large air gaps between movable and fixed surfaces, for large angular movements of the former away from neutral must be avoided, and where they exist should be suitably faired over.

Pilot's Control System

In small machines column control is used for both elevators and ailerons, but in large machines the lateral control is often effected by the rotation of a handwheel secured to the column head. Where dual control is fitted one column is usually designed to be readily removable; a single control column, cranked at the top, and capable of being swung to either side of the machine, is sometimes used where side by side seating is arranged. The close proximity of the control column to the compass and W./T. apparatus demands that it be made from a non-magnetic material to prevent it interfering with the efficient working of these units, and, to meet this requirement, a brass or duralumin tube is invariably used, which latter is often reinforced at its base by an internal liner to resist bending stresses due to elevator loads. The elevator control levers are frequently mounted upon an elevator cross-shaft extending across the width of the fuselage to the rear of the pilot's cockpit. Interconnection between control column and cross-shaft is then effected through a lever and connecting rod, the latter being provided with self-aligning ball-thrust races at each end to allow for the obliquity of the rod which occurs with sidewise movements of the stick. A torque tube usually connects the aileron control lever with the control column through a suitable coupling, the tube being supported by a journal type of thrust bearing designed to resist such thrust as may occur due to loads in the elevator circuit from a fore and aft movement of the stick.

The rudder is actuated by a rudder bar, or, in many large machines, by stirrup-type pedal control. To allow of fore and aft adjustment of the rudder bar, to accommodate a particular leg length, without alteration in cable lengths, the rudder lever is sometimes located at the lower end of a short vertical shaft supported in a bearing fixed to the floor of the machine. A slotted guide bar is secured to the head of the shaft and accommodates a sliding cross-head, to which the rudder bar is attached, thus allowing of a variable setting of the latter between the limits of travel of the cross-head. To ensure a sufficient sensitiveness of control at all flight speeds, without heaviness of control at high speeds or sloppiness at low, the elevator and rudder circuits are sometimes designed with a variable gear ratio between the angular travel of control column or rudder bar and the control surface, being as (say) 3 : 2 for initial displacements from neutral, and grading down to 2 : 3 as the controls approach the full throw of the system. Interconnection of the pilot's control system with the several control surfaces may be effected in various ways. In cases where a straight point-to-point connection is impracticable and where the control surface is situated some distance from the cockpit, extra flexible stranded cable is invariably used for the purpose; but in small machines a system of push-pull tubes is sometimes employed for the rudder and elevators, thus avoiding cable-stretch and cable-balance circuits,

reducing maintenance costs, and facilitating rigging. For cabin machines the rudder and elevator leads may be conveniently enclosed within a control duct secured to the cabin roof, a position where they are readily accessible for inspectional purposes, and where possible interference with passenger accommodation is eliminated. Moreover, in the case of flying boats, the duct affords a protection against corrosion from salt water spray. The run of the control cable is adequately supported by fibre or metal fairleads, and deviations from the straight and changes from one plane into another (as, for example, in the aileron circuit) are provided for by the fitting of duralumin control pulleys at such points as they occur.

Tailplane adjustment is usually effected by an application of the principle of the screw-jack, as used for lifting purposes. The tailplane may be pivoted about either spar, but it is preferable that the front spar be chosen for the hinge axis so that the surface shall be partially balanced, statically. A tubular adjusting strut, carrying a multiple start thread at its lower end, connects the tailplane with the operating gear; the rotation of an internally-threaded drum, meshing with the worm and located between horizontal faces of a suitable housing rigidly secured to the fuselage sternpost by a length of sprocket chain passing round an external sprocket wheel formed integral with the drum, imparts a vertical movement to the adjusting strut, effecting thereby a change of tail incidence. The drum sprocket is connected to a wheel control in the pilot's cockpit, the cable arrangement being such that a backward force at the top of the handwheel gives increased incidence to the tailplane, and corrects for tail heaviness, and *vice versa*. Because it ensures an irreversibility of control under all conditions of working, the screw-jack type of tail adjusting gear finds many applications in practice, and is particularly suited to machines of large carrying capacity, in which the tail area is often considerable. In some machines the screw-type of tail-adjusting gear, described above, is replaced by a direct-acting system of bell-crank levers and connecting rods. Quickness in operation and low cost of production are the principal recommending features of this arrangement, but these advantages are likely to be offset by control forces at the handwheel becoming excessively heavy, and a danger of creating tailplane flutter or vibration.

To facilitate assembly in the shops, the pilot's control system should, when possible, be so designed as to be self-contained, in order that it may be assembled to and removed from the machine as a complete unit.

THE USE OF MODELS IN RESEARCH AND DESIGN

BY

R. McKINNON WOOD, *Fellow, Member of Council*

*A paper read before the Bristol Branch of the Royal Aeronautical Society on October 18th, 1932**

If I wish to know the load which a structure will support without yielding or breaking, or its deflection under some load, I usually make calculations embodying numbers representing certain properties of the materials used, determined by some simple experiments. Sometimes the mathematics may be exceedingly difficult, or even intractable; or the mathematical solution may be achieved only at the expense of assumptions whose validity seems to need confirmation. I may then experiment with my structure, full scale; but it may be large and costly and I may wish to know the answer before I venture to build it. I may make a small scale model and experiment with that. Although I cannot solve my problem mathematically to my satisfaction, I can, from the nature of the equations involved, easily deduce the relations between my model experiment and the full scale. The accuracy of my method rests only upon the accuracy with which I reproduce the full-scale structure in the model.

I have given this as an example of the use of a model experiment in design; it rests upon principles with which every engineer is familiar. Structural questions are rarely treated in this way, because, as a rule, mathematics is so much easier than the model experiment. Aerodynamic problems belong to the other category; while there is useful scope for some crude computation in this field and sometimes for fairly accurate calculation, the mathematical solution is, in general, beyond our powers, and so model experiments play a large part in this field. I intend to review the various kinds of model experiments which are made, and to discuss the relations which obtain between them and the full scale.

Firstly, I shall consider the passage of a body through the air when the body is *free from acceleration, e.g.*, an aeroplane in straight flight at constant speed, and I shall develop my argument from the initial assumption that air is *incompressible* and *frictionless*. (Air is of course neither; this serves merely as a stepping-off point.) My method is that of Dimensional Theory, but I shall try to present it as unmathematically as I can.

It is usual to take, as the three fundamental *dimensions*, mass (M), length (L), and time (T); but it will suit us better to choose *density* ($\rho = M/L^3$), *length*, and *speed* ($V = L/T$). We have still three "dimensions" and each brings in a different one of the conventional three, M, L and T. Density will, for the moment, be the density of the air; L will represent the linear scale of our experiment, and V the speed of relative motion.

I will ask you to note in passing that the reaction between air and body can depend only upon relative motion. The motion of the earth in its orbit, the drift of the aeroplane in the wind are irrelevant; and so we may, for convenience, obtain the lift of a wing in flight from the lift of a model at rest in a stream of air, as we do in fact in our wind tunnels, provided we are concerned, as at present, only with unaccelerated flight.

* The author is alone responsible for the opinions and statements of the paper.

In our hypothetical air, incompressible and frictionless, the reactions must be related to changes in momentum of the air and to nothing else. Let us focus our attention on some little bit of air in our model experiment and on the corresponding bit in the corresponding full-scale event. Suppose that the air is ρ times as dense full scale; that the full-scale body is L times as long, etc., and that the relative speed is V times as great full scale. Then the rate of change of momentum of the full-scale bit of air will be $\rho \times L^3 \times V/T$ times that of the model bit. But $V/T = V^2/L$ and the force acting on the bit equals the rate of change of momentum. So the force is proportional to $\rho L^2 V^2$, *i.e.*, *density* times *area* times *square of speed*. You will notice that this is the quantity by which we are in the habit of dividing forces to form our force coefficients; our practice is based on this conception of an incompressible frictionless air, and in so far as our coefficients prove to be constants we say that there is no " scale effect."

I have assumed in my argument that the flow patterns are similar, model and full scale. You may accept this as a reasonable assumption: no reason can be adduced to show that the flow cannot be similar; and this assumption can, in fact, be justified by a more detailed analysis.

Now it may seem that the assumption of *incompressibility* would be reasonable when applied to a liquid, but questionable when applied to a gas. The validity of the assumption depends on the speed. Service aircraft now fly at about 200 m.p.h., and wind tunnel experiments indicate that their wings produce local increases and reductions of pressure of the order of 5 per cent. of the atmospheric pressure (actually about 100 lb. per sq. ft. at sea level where the atmospheric pressure is about one ton per sq. ft.) This gives us the order of the rarefaction or condensation of the atmosphere with which we are concerned; it must be remembered that it is fairly local and should not introduce so large an error in our results. In passing, I would, however, remark that we are now equipped with a tunnel at Farnborough with a speed of a little over 200 m.p.h. in which the effect could be studied.

When we come to consider airscrews the compressibility of the air may clearly be important. It becomes necessary, especially with tip speeds near 1,000 ft. per sec., to conduct the model experiments at the speed to be used full scale. To state this requirement more strictly, we must make the tests at the same ratio of the speed to the speed at which sound waves are propagated—the speed of sound varies with the temperature.

A series of experiments has been made with model airscrews with tips moving even faster than the speed of sound. The tests show that the " *compressibility effect* " becomes very big as the speed of sound is approached and that the efficiency of the airscrews fall. The effect becomes noticeable earlier with the thicker blades, and serious loss of efficiency can be postponed to speeds very near the speed of sound by the use of very thin blades. A sharp leading edge is beneficial at the speed of sound.

Passing now to *air friction*, a fluid differs from a solid in this, that no stress arises in it due to the shape of a bit of it having been changed; but stress does arise during the process of change and the shear stress is proportional to the rate of shearing. The " dimensions " of this stress are therefore $\mu V/L$, μ being the " *coefficient of viscosity*." We see then that we have in reality two sets of forces to consider:

Momentum forces.	*Viscous or friction forces.*
$\rho L^2 V^2$	$\mu L V$

Things may go wrong if these forces are not kept in the same proportion. We thus arrive at a criterion, namely that $\rho L V/\mu$ should be the same model and full scale. This quantity is known as " *Reynolds number*," after Osborne Reynolds. Since ρ and μ, being physical properties of the atmosphere, do not vary much

from one tunnel test to another, it has been quite usual to refer to the "LV" of a test; but the correct Reynolds number is to be preferred.

There is possibly some significance in the bigness of this number for a full-scale aeroplane: it is of the order of a million. It suggests that the viscous forces are insignificant beside the momentum forces. But this idea must not be stressed unduly; the size of the number depends on the linear dimension we insert in it, and this is rather arbitrary. If we treat air wholly as frictionless, mathematical solutions to our problems tumble out; but we find that bodies move through the air without resistance and wings will not lift. It seems we must pay attention to this Reynolds number, but we are at once in a difficulty. To test a fifth scale model in accordance with Reynolds' law we must use five times full-scale speed; to represent an aeroplane flying at 200 m.p.h. our tunnel must give us 1,000 m.p.h. Apart from the practical objections to building a tunnel of this capacity, the compressibility of the air would clearly vitiate the results, even for the representation of flight at more modest speeds.

The two solutions of this problem are:—

(1) The conduct of wind tunnel experiments, full scale or with nearly full scale (say half size) models, for which a 24 ft. diameter open-stream wind tunnel is being built at Farnborough.

(2) The use of a compressed air tunnel like that recently completed at Teddington.

The former has the advantage of allowing the use of actual aircraft and of greater facility of accurate reproduction in models. Even this large and costly plant will not deal with complete aircraft, and a still larger plant on the lines of the enormous 30 ft. by 60 ft. American tunnel is required to cover all work in this way. The compressed air system has the advantage of using small, and therefore cheaply and quickly made models; but it is also a costly piece of apparatus and one which is rather slow and difficult to operate owing to the time taken in filling and emptying and the inaccessibility of the model, etc., when working. Actually the Reynolds number attainable in this N.P.L. tunnel is about twice that which will be attainable with complete models in the R.A.E. large tunnel.

The principle of the compressed air tunnel will be readily followed from inspection of Reynolds number. The coefficient of viscosity is not much altered by the compression, the air being cooled before entering the chamber. An increase of density, say 10 times, counterbalances a reduction of scale to one-tenth. It is, however, convenient in practice to raise the density further—say, to 20 times atmospheric—and to halve the speed. Since the forces vary as ρl^2, this halves the forces, which are of course very high. The design of a tunnel of this kind must be based on compromise between the problem of containing the pressure and the problem of supporting the model and providing the power.

On these two lines the use of models is made in strict accordance with physical laws. Our large tunnel is being built primarily to meet difficulties of reproduction by models, *i.e.*, for testing actual aircraft; but the other is a means of complying with the law while still using small models. Its need had been felt for reasons that will appear later, but our small atmospheric tunnels give useful service and I must say something now of their scope and limitations. The theoretical approach to this subject is through understanding the mechanism of the action of viscosity.

The air touching a solid is presumably at rest on its surface. We may deduce this from our theory of the nature of matter; we may infer it from observation of flow very close to a body. The existence of viscosity means that the speed of flow must increase gradually as we pass out from the body into the stream;

actually it increases at a decreasing rate and the width of the belt of increasing speed is quite narrow. If the viscosity is high enough the flow is steady, but it becomes turbulent near the body when the viscosity is low. We call this belt the " boundary layer." It is a very thin layer at the nose of a streamline body, thickens as it passes along the body, and passes into a wake which trails behind. Confining attention to fairly high Reynolds numbers, we may say that viscosity is of importance within this thin layer and negligible outside. So the form of the flow round such a body as an airship hull and the distribution of the pressure over it may be expected to depend very little on viscosity except at the very tail where the wake streams off. The drag, however, will be much more sensitive to the value of viscosity. When the viscosity is high the boundary layer will be steady, or " laminar," and the drag coefficient will fall rapidly as the viscosity is reduced. At still lower viscosity the layer becomes turbulent—its nature depends more on the existence of some viscous action than on the actual amount and the drag coefficient approaches constancy. Between these two régimes, the drag coefficient is apt to be erratic; varying widely with slight changes of form, surface or turbulence of the air.

I have spoken of varying viscosity, but I have shown that it is on Reynolds number (R) that the phenomenon depends. Low viscosity means high Reynolds number. Raising the scale or the speed has the same effect as lowering the viscosity: both raise R, for $R=\rho LV/\mu$. Full-scale boundary layers are turbulent; wind-tunnel work is often in the erratic region. This is particularly so in the many tests of airship hulls which have been made and the tests of drag which have been made are of no use whatever in the design of airships. An airship model has been tested in many wind tunnels over the world with widely discordant results. On the other hand, other tests, such as pressure distribution over airship hulls, give useful results; and it is of interest to note that these results agree closely with figures calculated on the assumption of a frictionless air, except at the tail of the hull.

To obtain reasonably dependable results for the drag of an airship we must experiment on a larger scale than we have been wont to do. But there is a device which may enable us to counterfeit adequate scale with a still erratic Reynolds number. We may jog the boundary layer into early turbulence either by using a very turbulent airstream or by placing a fine thread round the nose of the model. This device only succeeds if we are reasonably near the scale for a naturally turbulent layer.

I must now pass on to consider the action of viscosity at sharp edges, and with particular reference to the trailing edge of a wing. If we work out the mathematical solution for a frictionless fluid we find that the fluid has an infinitely great speed at a sharp edge. Obviously the least trace of fluid friction will cause enormous forces here, and in fact whenever this tends to happen eddies are formed. Make a box with a sharp-edged orifice and a diaphragm lid. Tap the lid smartly and an energetic vortex ring is emitted. With this toy you may blow out a candle across a room. Or consider a disc moving broadside on; the air refuses to follow it round its edge, flows off its front in the plane of the disc at first, and leaves an eddying wake behind.

The theoretical frictionless fluid solution for a lifting wing is lift-less. The stream follows the under-surface round the trailing edge to meet the stream over the upper surface at a point on top of the wing. The existence of fluid friction demands that the whole flow be profoundly modified. The upper and lower streams must reunite at the trailing edge. This new flow pattern yields a lift. This lift we can calculate by frictionless theory if we assume what we call a " circulation round the wing." We know that this " circulation " could not come into being in a truly frictionless fluid; but we can account for its production by friction and then forget friction. We can experiment and see

the mechanism of its production. Draw a paddle through water: start the motion impulsively and you will see the eddy shed from its trailing edge marked by a dimple on the water surface. This eddy must be balanced by an equal and opposite circulation round the paddle.

Now this calculated lift is only a little greater than the actual lift. The difference is due to the boundary layer, which is thicker above the trailing edge than below it. The big departure from theory occurs when the wing stalls. The upper boundary layer has then got tired out and given up. A boundary layer will not follow a surface if it moves against too high a pressure gradient. This breakdown occurs in a pipe which expands too rapidly; the pipe will not "run full." The layer ceases to be a narrow boundary layer and becomes a wide belt of turbulence. The same thing occurs when a wing stalls. The aspect I wish to draw attention to here is that stalling is governed by the behaviour of the boundary layer, and in this layer the friction forces are important. We must, therefore expect "scale effect" on stalling.

As the pressure distribution round an airship is in good agreement with the calculated distribution except at the tail, so also does the pressure round a wing agree except near the trailing edge. The centre of pressure therefore shows a slight divergence from theory and is liable to scale effect. We can deduce that the scale effect on the hinge moment of an aileron will be rather greater, and that the scale effect on a narrow servo, balance, or trimming flap on an aileron may be very great. These narrow flaps appear in fact to be much more effective than our wind tunnel researches would lead us to expect.

To summarise, the small atmospheric wind tunnel is least reliable—and in fact quite unreliable—whenever stalling is involved. Apart from this it is good for lift, for pressure distribution (except at the tail), for finding the form of flow, downwash, etc.; not quite so good for centre of pressure. It is useful for the drag of fine streamline forms, if the scale be reasonably high and due allowance made for scale effect, in the light of our knowledge of the scale effect on skin friction and other researches: especially must allowance be made for scale effect on small parts such as interplane struts. Experiments have shown that big scale effects occur at higher Reynolds numbers on the thicker wings and bluffer streamline bodies. Very thin wings, in fact, seem to have little scale effect on maximum lift coefficient over the range that concerns us; but the thick wings are very troublesome. The compressed air tunnel has been built primarily for experiments with stalled wings.

I will pass on now to *gravity*, free-flight model experiments, and our new spinning tunnel. So far, I have allowed my craft no acceleration. In the tunnel it has been fixed to my balances; in flight the constraint has been hypothetical. I remove the constraint and *gravitational attraction* enters as a factor trying to produce a downward *acceleration* of 32.2 ft. per. sec. per sec. (g). All corresponding accelerations must be in the same proportion, model and full scale. The "dimensions" of acceleration are V^2/L; therefore, V^2/Lg must be the same, model and full scale. Since g is perforce the same, it follows that V^2/L must be the same. So if we produce an aerial manœuvre with a one-ninth scale model, it moves at one-third the speed, describing corresponding parts of the manœuvre in one-third the time, the scale of the model manœuvre being, of course, one-ninth the full-scale manœuvre.

I have now made an assertion as to what must happen; because the acceleration due to gravity has come in, the accelerations must be the same throughout, model and full scale. I have said that this must happen, but I have not mentioned anything that must be done to the model to achieve it. It is clear that I must make the *weight* of my model in the correct proportion to the *air forces*, *i.e.*, I must keep $\delta L^3 g/\rho L^2 V^2$ the same, δ being the density of the model. We now see

that the model must be so made that δ/ρ is the same. So, to represent a spin at sea level, I must give the model the density of the full scale aeroplane; for a spin at a greater height, I make it correspondingly less. And I must do this, in effect, in every part, which means in practice that the radii of gyration must be correct to scale and the total mass must be as the cube of the scale.

The models we use are made of Balsa wood, which weighs about 6 lb. per cubic foot. Fortunately there is no point in representing spins exactly at sea level, and the density of the model may be rather higher than that of the aeroplane; also the aircraft in which we are mostly interested are those with the denser wings. Even so it is not an easy matter to get the wings light enough, and we must sometimes cut out panels and cover with paper.

We started by dropping these models in a free spin in an old airship shed. We have now a much better technique. We launch them in a spin in an up-current in a vertical wind tunnel, 12 ft. across and 30 ft. high. The spin can be continued as long as we wish, and the model kept almost in one place and closely observed or cinematographed. We can also arrange that the controls are moved by a delay mechanism during the spin, and the recovery or failure to recover can be observed.

In this part of my discussion I have assumed that Reynolds number is not causing trouble and of course its value is low in this work. It will not surprise me if discrepancies between model and full-scale results occur. I only feel certain that the method is good for discovering or proving some general points. But so far the agreement between model and full-scale spinning experiments has been good and we have been encouraged to employ it as a guide and safeguard in all design for the R.A.F. where spinning qualities are of interest. It may not be infallible, but it provides, I think, a method of prediction well worth using.

Theoretically, we may treat other problems in this way. We could test the stability of an aeroplane by free flight models in normal flight. But in practice this does not seem feasible, because aircraft are excessively sensitive to the adjustment of the controls—the least error in rudder setting causes quite a steeply-banked turn; the least error in elevator a big change of speed.

It is possible for the wings or tail organs of an aeroplane to develop a violent oscillation in flight at high speeds; we call this "flutter." Wind tunnel experiments have been made in the course of enquiry into this phenomenon. The *elasticity* of the structure is a factor in the problem and must be correctly represented in the model. An exact copy of the full-scale structure should reproduce flutter at the same speed. Unfortunately, we have in the past not had sufficient speed available in our tunnels, but we have got round this difficulty, as I will show.

The forces involved are: (1) Rates of change of momentum of the wing (or tail); (2) air forces; (3) elastic forces. Keeping these in proportion means keeping the proportion:—

$$\delta V^2 L^2 : \rho V^2 L^2 : EL^2$$

where E is Young's Modulus; *i.e.*, the two ratios δ/ρ and E/V^2. The first is easy. If V must be less in the model test, we must make E actually, or virtually, less. We made V one-third, and being unable to use materials of one-ninth Young's Modulus, we made E *virtually* less by using spars of smaller scantlings and finer bracing wires.

In testing hulls and floats in a tank for seaplane design we have two main classes of work—the measurement of the forces in steady running, and the problem of stability of running or "porpoising." In the first class we are, of course, concerned with *viscosity*, and Reynolds number enters—the hull causes

surface waves, which are under *gravitational* influence, and so Froude's number V^2/Lg comes in; and finally there is *surface tension*, introducing a third number. We can only satisfy all these numbers at once by a full-scale test.

We have four kinds of force:—

(1) Rate of change of momentum of water ... $\rho V^2 L^2$
(2) Viscous force ... ... μVL
(3) Gravitational force ... ... $\rho g L^3$
(4) Surface tension ... ... τL

giving us three numbers $\frac{\rho VL}{\mu}, \frac{V^2}{Lg}, \frac{\rho V^2 L}{\tau}$.

When we come to the second class, a fourth number enters, the density ratio δ/ρ; *i.e.*, we must give our model the correct mass and moment of inertia about the axis of pitching. There are, however, further complications because the variation of the air forces as the aircraft oscillates may affect porpoising. Now it is the practice in ship-testing to conform to the Froude number (V^2/Lg) and experience has proved the necessity for this; surface tension is ignored and a skin friction correction is applied on account of the departure from the correct Reynolds number. In seaplane work the wave-making resistance has been deemed to be larger in relation to skin friction and this correction has been ignored. Surface tension is also ignored.

Designers have sought to avoid porpoising in the past on the basis of tests of hull models strictly suitable only for the other class of work. The mass and moment of inertia were far in excess of their correct values, and wings and tail were not represented. Recently, calculations of stability have been made assuming " derivatives " estimated as typical from crude hypotheses, with the object of getting some indication of the importance of various factors. It appears that the model must have the freedom to pitch and rise or fall which it always had, but that the third degree of freedom, variation of forward speed, may safely be omitted; this simplifies the tests very much. It appears to be quite important to give the model the correct radius of gyration, if not the correct mass also, and that the influence of the wings and, more especially, of the tail may be important, particularly when the hull is planing on one step. It is not difficult to give the model the correct mass and moment of inertia, to add wings and tail, and to give it freedom in pitch and vertical motion.

In discussing tank work I have ignored the fact that water is not incompressible, and I do not think you will take exception to this. But in the problem of the impact of a body on water we cannot do so, and we become concerned with a number of the E/V^2 form which occurred in the wing flutter problem. We can only satisfy this law by using the same speed, model and full scale. If we are to satisfy Froude's law too—as we presumably must—we are precluded from this use of the small-scale method entirely. It would seem, however, that when the impact velocity is quite low, we may get a good enough answer by following Froude's law; and that when it is quite high we may safely ignore this law and use the full-scale speed. I cannot, however, do much more than indicate the difficulty that arises here.

In this paper I have put before you the various " laws of dynamic similarity " which should govern the conduct of experiments with models to reduced scale in aero- and hydro-dynamics. You have seen that we are never able to conform strictly to them, and you will have realised that they are not just rules for deducing full-scale results from model tests, but laws which must, strictly speaking, be observed for deduction to be possible by them alone. To show, on theoretical grounds, why model tests which violate these laws may be of use,

we have had to enter into other considerations. Some of our transgressions we have lightly brushed aside, others have given us some trouble and we have only partially disposed of them. You will have appreciated the importance of correlative model and full-scale research in the various fields to give empiric backing to our somewhat sketchy frame of theory, and also the value of our new wind tunnels which conform more closely to the laws.

CORRESPONDENCE

London, October 8th, 1932.

The Editor, JOURNAL OF THE ROYAL AERONAUTICAL SOCIETY.

Dear Sir,—With reference to your review, in the October JOURNAL, of my book* "Aviation and the Aerodrome," it is perhaps due to my publishers to explain that I was not in any way limited by them in regard to space, and I should probably have anticipated your suggestion by including in the present treatise comprehensive descriptions of existing aerodromes in this country and abroad, but for the fact that many such descriptions have already appeared in technical journals. In my view, however, there have been so many mistakes made in the past when laying out and designing aerodromes that the purpose of my book was better served by describing from practical experience what I believe to be the correct lines upon which aerodrome design and construction must proceed from choice of site on to the completed aerodrome. The text is accompanied by 52 illustrations concluding with a layout of an imaginary civil airport which embodies the principles of design previously enunciated.

Yours faithfully,

H. A. LEWIS-DALE.

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* *Aviation and the Aerodrome*, by H. A. Lewis-Dale, London. Charles Griffin and Co., Ltd. Price 15/- net.

REVIEW

The Two-Cycle Engine

C. F. Caunter. Pitman & Sons. 15/- net.

This book is probably the only one so far published which deals with all types of two-stroke engines, from the miniature single-cylinder petrol units fitted in motor-cycles to large stationary engines. There is also a chapter dealing with aero engines of this type.

Mr. Caunter starts with a number of diagrams indicating graphically the various schemes on which such engines have been constructed. He explains the cylinder and port arrangements of crankcase compression engines of 2-, 3-, 4- and 6-port types, under-piston compression types, and various special designs some of which incorporate a method of mechanically withdrawing the burnt exhaust gas from the cylinder. Double piston engines are also explained.

The book is copiously illustrated with examples of most of the engines which have been commercially successful, and although he is himself an advocate of the two-stroke engine, he admits frankly the disadvantages possessed by many of these engines compared with similar engines of the four-stroke type while drawing attention to their advantages.

The simplest type is that frequently used in low-powered motor-cycles, and is characterised by the use of the crankcase for compressing the charge before it is injected into the cylinder, the ports for the transfer of the charge being arranged in the walls of the cylinder so that the piston itself acts as a valve. Engines of this type can be constructed with only three moving parts—piston, connecting rod and crankshaft—but it seems to be impossible to design the parts so as to obtain good scavenging of the cylinder without losing some of the incoming charge through the exhaust port. This direct loss of fuel is of little importance in a small unit intended for a motor-cycle, but cannot be tolerated in an engine of higher power. It can be obviated by using special and additional valve arrangements, but once these are added the engine loses its extreme simplicity, and with it one of its principal advantages over the four-stroke type.

The chapter dealing with two-stroke aero engines contains much that is of interest, and one would like to know how many of the engines described have passed type trials in the country of their origin; as far as one is aware, no two-stroke petrol engine has been submitted to this test in this country. Mr. Caunter is of the opinion that nearly double the power can be produced from a similar cylinder arranged to operate on a two-stroke cycle as compared with the usual four-stroke, but I do not share his opinion that such an engine could be satisfactorily air-cooled. It is known that, with the modern four-stroke aero engine, one of the most serious difficulties is the cooling of the cylinder and that many of the present engines are near to the limit of what is possible in this direction. There does not appear, therefore, to be any possibility of getting rid of, say, twice the amount of heat, and it would seem that such an engine would have to be water-cooled. This is not an insuperable disadvantage, but it must be balanced by adequate advantages in other directions.

Mr. Caunter has himself designed an aero engine of the five-cylinder radial air-cooled type, and an experimental model has been built giving about 50 h.p.

From his experience with this engine, Mr. Caunter states that a boosted and geared engine can be produced with a weight of 1½ to 1 lbs. per h.p. If he can get anywhere near the latter figure with a reasonable petrol consumption and the reliability necessary he should have the light aeroplane engine market at his feet.

He pays a well-earned tribute to Mr. Mort, whose water-cooled two-stroke petrol engine produced before the war was a brilliant example of ingenuity and skilled design, and it would seem that the figures given by these engines are generally as good as anything produced since.

Engines of the two-stroke Diesel type are also referred to. These are free from certain of the disadvantages of the two-stroke petrol engines, and if the Diesel type is to be used in aircraft, the two-stroke seems the most promising form. In fact the Junkers engine, which has been more exclusively used than any other, is a two-stroke.

The book should be read by all those interested in the development of the explosion engine.